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ENVIRONMENTAL MONOGRAPH NO. 10

Report of a Workshop: The Case for Integrated Models of Acidic Deposition in Canadian Environmental Policy Making

Editor: R.E. Munn

Institute for Environmental Studies
Institut pour l'Etude de l'Environnement

ISSN 0710-6815
ISBN 0-7727-4411-4

REPORT OF A WORKSHOP: THE CASE FOR INTEGRATED MODELS OF ACIDIC DEPOSITION IN CANADIAN ENVIRONMENTAL POLICY MAKING

TORONTO, APRIL 25-26, 1989

EDITOR: R.E. MUNN

Environmental Monograph No. 10

Institute for Environmental Studies
University of Toronto
Toronto, Canada
M5S 1A4

February 1990

Pub. No. EM-10

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Printed in Canada
University of Toronto Press

ISSM 0710-6815
ISBN 0-7727-4409-2

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EXECUTIVE SUMMARY

A Workshop on Integrated Models of Acidic Deposition was held at the University of Toronto, April 25-26, 1989, sponsored by Environment Canada (Conservation and Protection). The main emphasis was on the credibility gap between modellers and users, particularly with respect to policy applications. An integrated model (IM) was taken to mean a model that contained a series of submodels related along a causality chain. Typical components that might be linked together include submodels of emissions, atmospheric processes, receptor effects, economic effects, emission controls/damage mitigation and policy initiatives/responses.

This monograph is a report of the Workshop. In Section 2, some typical Canadian IMs of acidic deposition are described. Then in Sections 3-9, the Workshop results are given, which can be summarized as follows:

There is need to distinguish between research-directed and policy-directed IMs. In both cases, an IM can help greatly in clarifying complex inter-relations. With respect to policy analysis, an IM is also particularly useful in rapidly answering "what if" questions regarding the costs and benefits of alternative policy options. A properly designed IM can also bracket the uncertainty in the answers given.

Time windows of opportunity exist, when policy makers can use and indeed would welcome input from IMs. Continuing dialogue is needed between policy makers and scientists to identify these windows several years in advance.

Linkages between the acidification issue and other environmental problems should be given special attention, noting in the case of forests, for example, that damage can be caused not only by acidic deposition but also be ozone episodes, insect infestation, poor forest management, and, over the long term, climate change. Thus, modellers should begin to think about constructing IMs that integrate laterally over a range of stresses imposed on sensitive receptors. Of course, priority should be given to the design of IMs that assume that acidic deposition is the only stressor.

Modellers should pay more attention to the issue of model credibility. One way of achieving this is to involve users in model design and development, and greater emphasis should be given to designing more illuminating graphical displays.

Although considerable work has been undertaken to test the performance of individual modules in an acidification IM, there is an urgent need to test the performance of an IM as a whole.

FOREWORD

A workshop on "Integrated Models of Acidic Deposition" was held at the Institute for Environmental Studies, University of Toronto, April 25-26, 1989. The emphasis was on Canadian experience and needs for integrated models of acidic deposition. However, Marylynn Placet provided a U.S. perspective, while Roderick Shaw discussed the European RAINS model. Peter Loucks, Cornell University, contributed his experience in the use of integrated models in the water resource field.

This monograph synthesizes the numerous ideas that flowed from the Workshop. A first draft was sent for comment to participants as well as to a few other persons. So the monograph represents a first-order consensus, although the Editor takes responsibility for the final text.

The Workshop was organized by a Steering Committee, consisting of:

Dr. T. Brydges, Environment Canada
Dr. P. Cohen, Environment Canada
Dr. R.E. Munn, University of Toronto
Dr. D.M. Whelpdale, University of Toronto/Environment Canada

The program for the Workshop is in Appendix 1, and the list of participants is in Appendix 2. Two of the papers presented on the first day are given in Appendices 3 and 4.

Finally, it should be noted that because the intended readers of this monograph include both modellers and users, and because some of the latter have limited computer backgrounds, technical terms will be avoided.

R.E. Munn, Editor

ACKNOWLEDGEMENTS

The financial support of Environment Canada (Conservation and Protection) is gratefully acknowledged.

Thanks are given to Workshop participants for their obvious enthusiasm and for the many insights that they shared. Special mention should be made of the chairmen, Doug Whelpdale and John Hollins, and rapporteurs, Dean Jeffries and Sherri Watson, of the parallel discussion groups held on the second day of the Workshop.

Technical assistance was ably and cheerfully provided by Chris Radewych and Mona El-Haddad. The subsequent camera-ready manuscript was prepared by Julie Berridge and Johanna Retèl. The contributions of these people are greatly appreciated.

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1. INTRODUCTION

A Workshop on Integrated Models (IMs) of Acidic Deposition was held at the University of Toronto, April 25-26, 1989. An IM is defined as a system of models which are interconnected causally (Olsthoorn et al. 1989). Figure 1 shows a simplified schema of such a system but each box in the diagram could be further subdivided, and other boxes could be added - boxes for energy policy and control costs (on the left side of Fig. 1), and boxes for impacts on agriculture, human health and wildlife (towards the right side of the figure). Each box represents a component model which often contains some very complex biology, physics, chemistry, economics or engineering. As pointed out by Rubin (1989), IMs broaden the perspective of researchers, and increase the usefulness of model output for policy analysts.

The workshop participants could not agree entirely on the definition of an IM. There was consensus that an IM should at the very least consist of two or more modules coupled together in series as in Fig. 1. However, some participants felt that IMs should also include feedbacks; otherwise the term linked models seemed more appropriate. Hereafter in this report, however, the two terms will be used interchangeably.

Two other points need to be mentioned in connection with Fig. 1. In the first place, receptors are affected not only by acidic deposition but by many other phenomena; for example, forests are stressed by climate warming, drought, pests and over-harvesting, as well as by acidic deposition.

Secondly, there are different kinds of receptors (lakes, forests, buildings, etc.), and these are affected differently by the same amounts of acidic deposition. So if one were interested in connecting all of the submodels in Fig. 1, beginning with emissions and continuing through to socioeconomic consequences, one would need individual IMs for lakes, forests and buildings.

In Canada, IMs of acidic deposition have not been as widely adopted as many modellers would have wished[1]. One of the objectives of the Toronto Workshop was, therefore, to make the case for greater use of IMs in Canada.

This account of the Workshop begins (Section 2) with descriptions of some typical IMs of acidic deposition that have been developed in Canada, as well as one from Europe. Subsequent sections seek answers to questions posed to two discussion groups at the Toronto Workshop.

* What are the potential benefits to be gained from IMs?
* What model components and field data are of most importance if IMs are to realize their potential?
* Has satisfactory model performance been demonstrated?
* Have the IMs been accepted by the intended users? If not, why not?
* What is the possibility of standardization to produce only one or a few IMs?
* What must be done to improve the present situation?
* How should this be achieved?

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[1]This problem does not occur to such an extent in Europe, and in some other environmental fields, e.g. water pollution control.

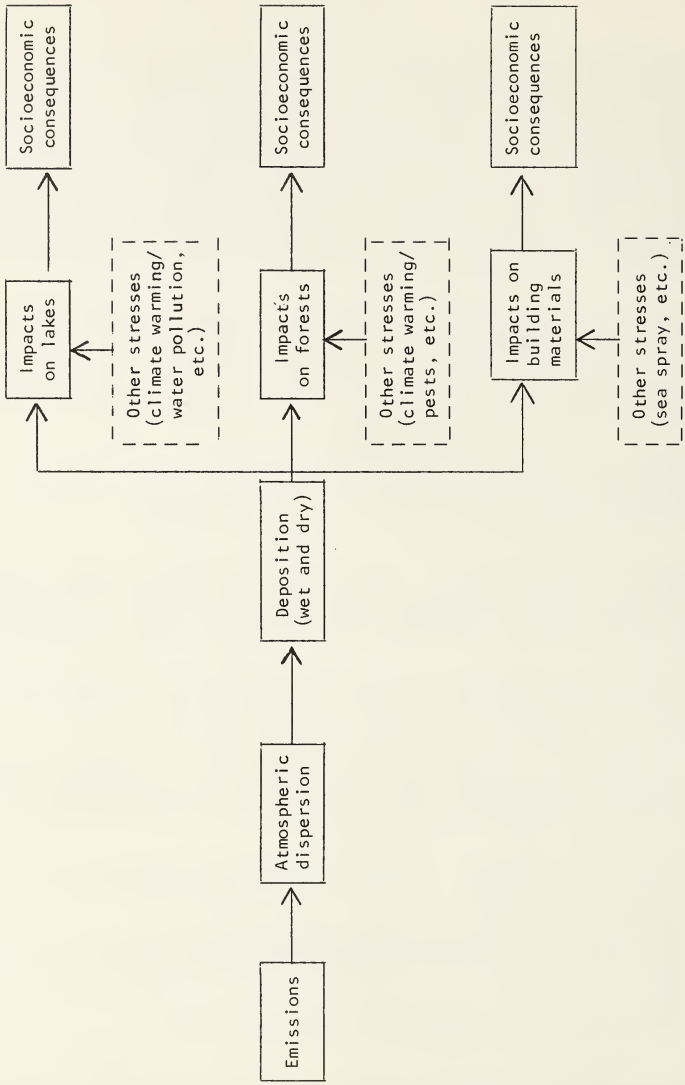

Fig. 1. A schematic presentation of the various components involved in the acidification issue

2. SOME INTEGRATED MODELS OF ACIDIC DEPOSITION

2.1 A CONCEPTUAL FRAMEWORK

Figure 1 provided a simplified example of an IM. However, a better conceptual framework, including feedbacks, is shown in Fig. 2 (Streets 1988). The six modules displayed in Fig. 2 are:

1. an emission module;
2. an atmospheric module (transport, diffusion, chemical transformations and deposition;
3. a receptor effects module;
4. an economic module;
5. an emission-control/damage-mitigation module;
6. a policy module.

Note that some kinds of receptor damage can be costed, permitting connections to be made from module 3 to 4 to 6. However, because some kinds of damage cannot be costed (e.g. number of acidified lakes), the flow chart also goes directly from module 3 to module 6. This represents a central dilemma for the policy analyst - how to compare damages that can be costed with damages that cannot.

2.2 SOME CANADIAN INTEGRATED MODELS OF ACIDIC DEPOSITION

In Appendix 4, Cohen has provided a useful list of IMs of acidic deposition. Some of the Canadian IMs and one European one on Cohen's list will be described in this section. Although none is as comprehensive as that shown in Fig. 2, and although none contains feedbacks, the models do include modules that are connected along causality chains.

(a) The Memorandum of Intent Model

As part of the assessment undertaken in connection with the United States-Canada Memorandum of Intent (MOI) on Transboundary Air Pollution, a target loading of 20 kg/ha/yr for sulphates in precipitation was established (Bangay and Riordan 1983) for lakes and rivers in the Laurentian Shield of Eastern North America. Much of the assessment was undertaken by T. Brydges and F. Elder, who examined the data available at that time on wet deposition, loss of alkalinity and aquatic effects in both Canadian and United States lakes and rivers. The result was a combination of empirical data supported by statistical model results. (See page 37 for further details.)

The MOI "model" was developed for policy applications but it also stimulated the research community to design experiments to test the target loading concept.

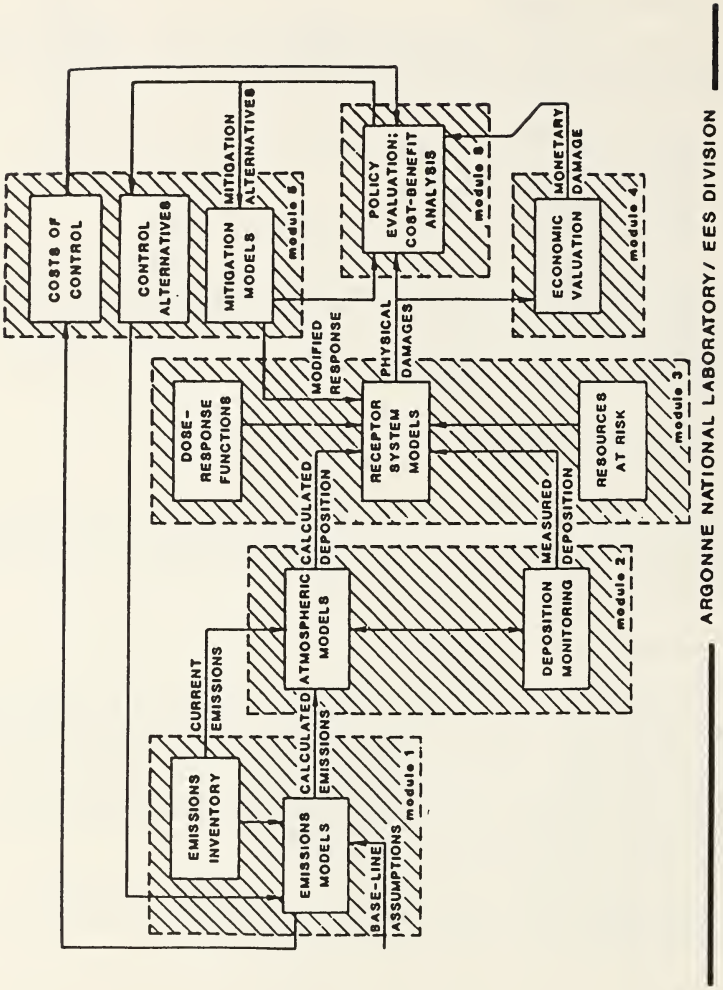

Fig. 2. An ideal integrated assessment framework
Source: Streets 1988

(b) The Young-Shaw methodology

Once a target loading for wet deposition of sulphur has been selected, the question arises as to how best to reduce sulphur emissions in order to meet this target loading. The optimization may be performed with respect to minimizing the amount of sulphur removed or minimizing the cost of removal.

A methodology was developed by Young and Shaw (1986) for minimizing the amount of sulphur removed and by Shaw (1986) for minimizing the cost of sulphur removal. In both cases, a background wet deposition of 6 kg sulphate/ha/yr was assumed. Then for 9 sensitive receptor points (see Fig. 3), the contribution from each of 40 source regions (see Fig. 3) was estimated using a long-range transport model, and the results were expressed in terms of so-called transfer matrices. For the sulphur removal minimization (Young and Shaw 1986), four schemes were tested, one of which included reasonable constraints on the amount of sulphur that could be removed from individual regions on technological or economic grounds. All four schemes indicated that most of the sulphur emission reduction should take place in the Ohio River Valley, northern Appalachia, the lower Great Lakes region, and the Provinces of Ontario and Québec.

For the cost-minimization problem (Shaw 1986), the methodology was similar but the analysis used information on control costs for various levels of control and various types of point sources (smelters, thermal generating stations, and fuel oil desulphurization installations). The interesting result was obtained that costs estimated in this way were less than in the case of minimization of the additional sulphur removed.

The Young-Shaw results provided the basis for Canadian federal policy on acidic deposition, and were used in negotiations with the United States.

(c) The Ontario screening model

The Ontario screening model is a linear programming model for acid rain abatement (Ellis *et al.* 1985; 1986; McBean 1987), which interfaces with the Ontario Ministry of the Environment's long-range transport model (Venkatram *et al.* 1982). A cost-of-control module is also used. (The cost of controlling sulphur emissions increases as more and more sulphur is removed. The cost also depends on the nature of the source.)

The system selected for analysis included 235 large controllable point sources of sulphur and 83 uncontrollable area sources over Eastern North America. The linear programming model then determined the least-cost reduction of SO_2 emissions to meet a predesignated annual deposition at 20 sensitive receptor locations. As might be expected, the most cost-effective strategy is to reduce emissions first at facilities where control costs are least. Through an iterative process, more and more of the point sources are required to control their emissions. The approach developed by Ellis *et al.* (1985; 1986) leads to strategies that are much more cost effective than that of imposing across-the-board removals.

Fig. 3. The 40 source regions and the 9 sensitive receptor points as designated by the modellers working under the United States-Canada Memorandum of Intent on Transboundary Air Pollution
Source: Young and Shaw 1986

(d) DFO-ESSA lake chemistry model[2]

A regional simulation model has been constructed for the purpose of examining the eventual (long-term) distributions of alkalinity and pH in Canadian lakes, given specified levels of sulphate deposition (Marmorek et al. 1989; Jones et al. 1989). The model is deliberately kept simple so that it can be used on a regional scale without excessive input data. The outputs are, therefore, given as median predicted regional values of eventual alkalinity and pH. Atmospheric inputs to the model are provided by the transfer matrix derived from the Atmospheric Environment Service long-range transport model.

Model performance was tested on current data in the Sudbury region and found to be satisfactory in that case. Then for three emission scenarios, eventual alkalinities and pH were derived. The results are presented in terms of percentages of lakes with predicted eventual alkalinity less than zero and pH less than 5.0, 5.5 and 6.0 separately in Ontario, Québec and the Maritimes.

As the authors emphasize, the policy-oriented approach taken is unique. Other regional models of acidic deposition in North America "are either not designed to examine the consequences of alternative control strategies or do not predict the consequences of control measures in terms of ecological damage" (Jones et al. 1989).

As an extension of the DFO-ESSA lake chemistry model, a linked model of biotic damage has been added (Minns et al. 1989). Biotic damage was estimated using a model of percent loss of species richness in seven taxonomic groups based on observed distributions of minimum pHs at which the species occurred. The model simulations show that even with a reduction of 42% in 1989 sulphur emissions in the U.S. and Canada, biotic damage can still be expected in about 25,000 lakes.

Although policy-oriented, the DFO-ESSA IM has not yet been used by policy people to any extent.

(e) A regional model of acidification effects on waterfowl

In October 1987, the Canada Wildlife Service sponsored a workshop to consider the feasibility of adding a waterfowl effects module to existing regional acidification models of water chemistry in eastern Canada. Based on the ideas brought forward at that workshop, Jones and Wedeles (1989) have developed a prototype module that is currently being tested.

Using data collected in two regions in Northern Ontario - from 33 lakes in the Ranger Lake area (moderate sulphate deposition) and 53 lakes in the Wanapitei area (heavier sulphate deposition), Jones and Wedeles have established a statistically significant correlation amongst lake size, lake chemistry (Ca, Mg, SO_4, total cations and DOC), and waterfowl indicators (species, number of pairs, number of chicks).

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[2] DFO is the Department of Fisheries and Oceans; ESSA is the Environmental and Social Systems Analysts Ltd.

The next step in the analysis was to apply the regional water chemistry model of Marmorek et al. (1989) to predict the distribution of pH and alkalinity for given emission scenarios, and to estimate the impact on waterfowl, using the correlations obtained from the Northern Ontario data.

The approach is promising although the statistically based predictions still need to be tested with an independent set of lake chemistry and waterfowl data.

(f) RAISON - an expert system approach

When studying the regional impact of acidic deposition on watersheds, one often finds that the available data are inadequate, having been collected in only some of the watersheds in the region, and at different times. In such situations, the "expert system" approach is often helpful, providing a means to exploit existing knowledge and data bases garnered from a variety of sources. Such a system RAISON has been developed and tested by Lam et al. (1987; 1988; 1989).

RAISON is a microcomputer-based system which processes data and selects appropriate models according to knowledge rules provided by expert scientists. Missing data on water chemistry in a given watershed, for example, can be estimated by searching for other watersheds with similar soil characteristics and vegetation cover for which data are available. For southern Québec (Lam et at. 1988) and New Brunswick (Lam et al. 1989) the predictions of soil acidification obtained by selectively choosing between two models (the cation denudation model and the trickle-down model) were better than those obtained from either model in data-rich watersheds. An extension to the regional data-poor scale was possible through matching watersheds with similar soil characteristics.

RAISON has not yet been applied to policy formulation. However, it has already been shown to be an extremely useful tool for organizing knowledge and data files derived from disparate sources, and for identifying research and monitoring priorities.

2.3 THE IIASA EUROPEAN RAINS MODEL

The IIASA model of acidic deposition is included in this survey because it is a good example of a policy-directed IM that is actually being used, and because it was frequently mentioned at the Toronto Workshop.

RAINS (Regional Acidification Information and Simulation) was developed over several years at IIASA (International Institute for Applied Systems Analysis - Laxenburg, Austria) (Alcamo et al. 1987). A schematic overview of the RAINS modules is shown in Fig. 4. At present RAINS is restricted to sulphur but work is proceeding to add NO_x to the system.

As the figure indicates, the model can be used in two ways.

1. Having selected an energy pathway for the next several decades, the resulting effects on European groundwater, lakes and forests can be estimated (scenario analysis).

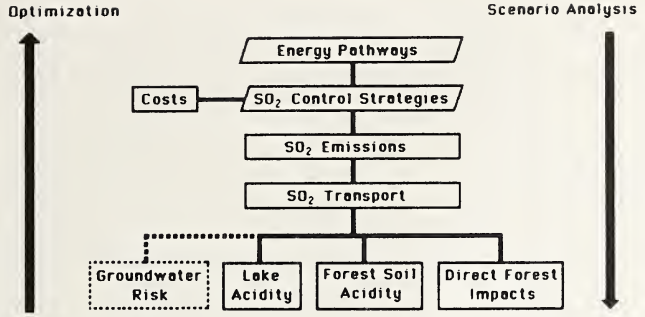

Fig. 4. A schematic overview of the RAINS model
Source: Alcamo et al. 1987

2. Beginning with a desired state of European lakes and forests, in the year 2030 say, optimal control strategies for sulphur emissions can be devised. These take into account the many sulphur sources existing across Europe and the very considerable differences in emission control costs that exist from country to country, from industry to industry, and from a low to a high degree of control (optimization analysis).

The SO_2 transport module used in RAINS is based on the EMEP[3] model (Eliassen and Saltbones 1983) giving a transfer matrix relating sulphur emissions to SO_2 air concentrations and sulphate depositions on a country-by-country basis. The matrix was developed at the ECE EMEP Meteorological Synthesizing Centre West in Oslo, Norway.

The model has been used as a policy tool at meetings sponsored by the ECE, and more than 50 copies of the computer software have been sold to governmental bodies and research institutes.

Two additional points are worth noting:

1. Each module has been peer-reviewed at small workshops attended by specialists from the relevant disciplines.
2. Sensitivity analyses of the IM have been undertaken (Alcamo and Bartnicki 1987) and the results discussed with small groups of experts.

This process of external reviews accounts in part for the wide acceptance that RAINS has received.

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[3]EMEP is the European Monitoring and Evaluation Programme.

3. POTENTIAL BENEFITS OF INTEGRATED MODELS OF ACIDIC DEPOSITION

At the outset it should be emphasized that many of the possible users of IMs do not realize the potential value of such models. This is largely because of the communication gap between modellers and users, a problem to be discussed later in Section 7. If that problem could be overcome, what would be the benefits to be derived from IMs?

The Toronto Workshop participants agreed on the following:

1. Some general benefits

Even if only a couple of the modules in Fig. 2 were included in an IM of acidic deposition, the system would still contain some very complex physics, chemistry, biology and perhaps technology and socio-economics. However, the essential components of the processes involved can be captured in a short-hand way with an IM permitting rapid assessment of the effects of changing system inputs or model assumptions. Such an exploration would be difficult, expensive, time-consuming and in some cases impossible to undertake in the natural environment.

A second general benefit to be derived from IMs relates to improved communication amongst disciplines and areas of responsibilities. Once the connections have been established amongst the various modules shown in Fig. 2, a common understanding of the essential issues is likely to evolve.

2. Benefits to policy people

The main goal of policy analysis is to characterize the costs and benefits of alternative policy options. Whereas the results of scientific research are usually given in technical language, policy analysis must be expressed in a non-specialist form. Streets (1989) suggests, therefore, that an integrated assessment is a valuable translator. "It can find the essential truth in a wealth of scientific detail and convey meaning and context to the policy analyst" (Streets 1989).

An IM of acidic deposition can assist policy analysts in the following tasks:

(a) the development of abatement strategies;
(b) the resolution of conflicts (interprovincial, intergovernmental, governmental-industrial, etc.);
(c) the provision of answers to "what if" questions, as input to policy development;
(d) the identification of new issues, and elaboration of appropriate methodologies;
(e) the rationalization and coordination of multi-media monitoring systems;
(f) the allocation of funds amongst research groups.

Some of the key "what if" questions that an integrated model of acidic deposition could help to answer for Canadian policy-makers are:

1. Given maximum annual rates of acidic deposition designed to protect sensitive receptors, what regional strategies should be adopted for sulphur emission reduction (minimizing the cost of sulphur reduction or the amount of sulphur removed)?

2. Is it essential that major cuts in sulphur emissions be made immediately or would a staged reduction program be acceptable? (This question involves the issues of time lags and irreversibility.)

3. From time to time, new policy options for air pollution control are proposed by the White House or the U.S. Senate. What would be the ecological effects of these options on acid deposition in Canada?

4. What is the range of uncertainty in each of several "what if" simulations of the effects of a range of policy options?

3. Benefits to research managers

An IM of acidic deposition can help in the identification of research gaps and cross-sectoral linkages. Thus an IM can provide a valuable framework for the development and justification of integrated research and monitoring programs. This includes the establishment of funding priorities (see Section 5 of Appendix 4).

4. Benefits to educators

An IM is a tool for teaching students to look beyond the borders of their own disciplines. (See Section 4.2.3. of Appendix 3.) An IM provides a means for investigating interdisciplinary relationships, demonstrating the interconnectedness of the various facets of an issue (e.g. the relationships between changes in emissions and changes in effects). As well, IMs promote an understanding of uncertainty, including the way it propagates through a system, and provide a focus for cross-disciplinary cross-sectoral discussions on science policy.

4. ASSIGNING PRIORITIES AMONGST COMPONENTS OF IMs OF ACIDIC DEPOSITION

4.1 GENERAL

In terms of the framework in Fig. 2 for IMs of acidic deposition, which modules are of most importance? Of course, priorities are somewhat dependent on the nature of the questions that the IMs are expected to answer, and these questions vary greatly with respect to space scale, time horizon, sector (environmental, economic, social) and application (scientific, policy-related). The IM model itself can provide guidance - certainly with respect to data needs of highest priority but, to date, this opportunity has not been taken up to any extent. Unfortunately, priorities are often decided in a disjointed and parochial manner.

4.2 SCIENTIFIC APPLICATIONS

With respect to scientific application of IMs, some modules have been reasonably well studied, while others have not. Two major areas that should be emphasized in future studies are:

1. Research related to the interfaces between modules. Problems may exist because of incompatible data banks or differing space and time resolutions of the data. There may also be differing depths of understanding of the nature of interface processes; this sometimes is clouded by arguments about "turf" and associated financial resources.

2. Research related to feedbacks. Particularly with respect to long-term studies, feedbacks may play an essential role in the behaviour of the system being modelled.

4.3 POLICY APPLICATIONS

At the Toronto Workshop, representatives from the policy community felt that the outputs of IMs should not be very complex, if they were to be used as policy tools. They argued that one should seek a "common denominator" of understanding amongst the modules of relevance to the particular issue at hand. But as has been demonstrated in the water quality field and with the European acid rain model RAINS, outputs can be presented in readily understandable form without sacrificing the complexity of component parts of an IM.

Of more importance, therefore, is that the likely policy questions be identified in advance. Working back through the IM then, one should ask of each module: what outputs are needed, and with what precision and accuracy?

4.4 PRIORITIES FOR DATA

It is important to differentiate between input data (required to develop the IM) and evaluation data (required to test model predictions). Evaluation data will be discussed in Section 5. With respect to input data, the point should be made that modelling and monitoring are iterative processes. The first model constructed is usually very simple but it identifies the data required to build a "next-generation" model. Acidic deposition models have, of course, gone through many iterations over the last two decades, and appropriate input data have been obtained in most cases to meet the changing needs of the modellers.

A final point to be made is that common input data sets should be used wherever possible. This is particularly the case when the models are designed for policy applications.

5. MODEL PERFORMANCE

5.1 INTRODUCTION

One of the reasons given by potential model users for their lack of enthusiasm is that although computers are admittedly good "number-crunchers", the validity of the outputs has not been demonstrated to their satisfaction. For example, when policy people are considering alternatives, can model outputs discriminate with sufficient confidence to warrant selection of one or two

amongst several courses of action? In this section, the methods used to evaluate model performance are discussed. Additional information is given in Appendix 3, Section 3.

5.2 MODEL PERFORMANCE

Model performance can be evaluated in three ways:

1. statistical tests, i.e. by comparing model predictions with observations. Because of the natural variability in the environment, and because of possible bias in observational network data, model performance assessments based on statistical tests cannot be very precise.

2. sensitivity analysis, i.e. by changing model input values, and noting the robustness of model output values to these changes.

3. scientific consensus, i.e. by peer review in which agreement is reached that all of the important processes have been included in the model and that the outputs are reasonable.

Models are often used to provide predictions for conditions well beyond the range of data used to develop the model. If, for example, a particular synoptic weather pattern were not included in the input file, could the model be trusted to give reasonable results in such conditions? Thus it is that modellers recommend that an array of performance tests be used wherever possible.

With respect to the various modules that could be included in an IM of acidic deposition, the atmospheric module is the one for which model performance has been most widely tested. In 1982, for example, a joint U.S.-Canada Work Group assessed the outputs of eight regional models, comparing modelled concentrations and depositions from model to model and with observations (Schiermeier and Misra 1983). More recently, 11 models have been compared (Voldner et al. 1988; Clark et al. 1989). (In this latter assessment, one of the conclusions was that seasonal average predicted concentrations of sulphur dioxide and sulphates at four Canadian monitoring stations were mostly within a factor of two of observed values. This is typical of the kind of conclusion to be found in such studies.)

With respect to the other IM modules, there have been less but nevertheless significant amounts of model performance testing. Certainly in terms of the "scientific consensus" approach to model validation, there have been no sharp disputes amongst Canadian and U.S. scientists in the same disciplines.

Although individual modules have been subject to considerable scrutiny, there remains the important task of testing the performance of integrated models containing several modules, particularly when feedbacks are included. The Toronto Workshop participants believed this to be a priority item. In this connection, Rubin (1989) has described some methods currently being used to characterize uncertainty in IMs, using as examples, 2 American and 3 European IMs of acidic deposition (including RAINS).

5.3 DATA NEEDS FOR MODEL PERFORMANCE TESTING

Data needs are clearly linked to the intended application. In some cases, it may be difficult or impossible to test an IM (with feedbacks) with experimental data in a reasonable length of time. Then the methods of sensitivity analysis and scientific consensus should be used. This is a point not well understood by policy people, who may ask to see the results of comparisons of observations with predictions.

Even if data are to be used for statistical testing of model performance, there are many kinds of statistical tests (see Munn et al. 1988, for example), and the design of a protocol is somewhat subjective. Traditionally, the approach used is to seek a consensus amongst modellers on the most appropriate statistical tests to be applied. For policy applications, greater efforts should be made to involve the policy people in this process.

6. USER ACCEPTANCE OF INTEGRATED MODELS

6.1 THE ISSUE

In North America in the acidic deposition field, there is a credibility gap between modellers and many potential users. The word "credibility" is, of course, inappropriate in some cases. Rather, the modeller has been unable to capture the attention of potential users, for a variety of reasons, and thus to demonstrate the utility of the models on offer. This is not a situation unique in the field of acidic deposition in Canada but occurs through many environmental areas and in many countries; see for example, Frenkiel and Goodall (1978). There are several reasons for the credibility gap that sometimes exists between modellers and users:

1. The uncertainty in the outputs from IMs is sometimes not well specified, particularly in the case of simulations of conditions that have not occurred historically (e.g. climate warming).

2. IM outputs are not always well packaged. (Model assumptions and linkages between modules may not be transparent; model outputs may be too technical or may provide surplus irrelevant information.)

3. IMs are sometimes used in a work environment not appropriate to achieving dialogue between modellers and users, e.g. in a line-management rather than a round-table setting.

4. IMs often include submodels drawn from several disciplines cutting across academic or departmental boundaries. The resulting arguments about "turf", with associated staff and funding implications, are not conducive to integration.

5. Modellers do not always appreciate the needs and limitations of potential users, and users may have an inadequate appreciation of modellers' capabilities.

6. Modellers do not always appreciate the fact that IMs do not drive the decision-making process; rather, IMs are tools that are supportive of this process.

7. IMs are often built to meet specific user needs. Over the years these needs may change but the models may not.

6.2 SCIENTIFIC APPLICATIONS

User acceptance of a research-oriented model requires first that a paper describing the model be accepted for publication in a peer-reviewed journal. Subsequent citation by other authors is further evidence of user acceptability, particularly if the citations are by scientists in other disciplines. In the case of IMs, if model outputs are used as inputs to another model with reasonable success, then the first of these models can certainly be deemed to have received user acceptance. Of course, the model outputs may have been used for lack of anything better but this is an appropriate procedure during the process of model development. The source-receptor matrices developed for Europe are model outputs that have attained user acceptance (see Section 2.3).

A more difficult characteristic to evaluate is the degree to which an IM has contributed to establishing priorities for interdisciplinary research. The originators of the various models described in Section 3.2 were queried on this point, but no documented examples could be cited.

6.3 POLICY APPLICATIONS

The points given above apply also in the case of user acceptance by the policy community. But added to the list of characteristics of a successful IM must be:

* simplicity
* specificity
* transparency
* flexibility
* attractiveness of visual displays.

For policy people, IMs must be capable of responding quickly to a variety of scenarios comparing alternatives in ways that are meaningful to non-specialists. For example, graphic displays of changes in the pHs of lakes and soils cannot be used directly in the development of emission reduction policies. Instead, information is needed on the comparative ecological damage (number of species expected to become extinct, for example) associated with a range of emission control policies.

Another point raised by Loucks et al. (1985) is that policy people want information on "who cares and how much, as well as information on physical and economic impacts". In the universe of IMs, this issue has hardly ever been addressed. However, there is no doubt that social scientists have an important role to play in terms of the "who cares" problem, although their contribution to the development of IMs remains uncertain.

A final point needs to be made, namely, that even if all the preconditions listed above are met, an IM may still not be accepted for policy formulations if:

* there is insufficient regular communication between modellers and policy people;
* there is resistance to innovation by policy people for institutional or political reasons, for example.

In Canada, there has not been much opportunity to test user acceptance of policy-related IMs, largely because the models have not been developed in time to be used in the decision-making process. However, the Young-Shaw model (see Section 2.2) was used to set Canadian policy in the acidic deposition issue; it was also used in Canada-U.S. negotiations. In these cases, of course, user acceptance was in terms of scientific advice rather than specific outputs from a model. In Europe, the RAINS model has been used as a decision support system by the ECE.

In this connection, timing is of the essence. In many cases, of course, scientists are the first people to identify an emerging environmental issue. Ultimately, however, in a few years (or occasionally only a few months) the issue will reach the political agenda, or will re-appear on that agenda. That is an important moment. One of the Workshop speakers, A. Manson, emphasized that there are "time windows of opportunity" when public policy-makers can use and indeed would welcome inputs from IMs. Once a major decision (e.g. to reduce sulphur emissions by 50%) has been made, however, the possibility that the decision will be modified over the short to medium term (1 to 5 years) is usually rather slight, no matter what the outputs from IMs might be. Occurrence of these windows of opportunity is not entirely random. Thus, continuing dialogue between policy people and scientists is essential if IMs are to play a meaningful role in policy formulation.

6.4 USER ACCEPTANCE BY GRADUATE STUDENTS

As pointed out by Whelpdale (see Section 4.2.3 in Appendix 3), one of the most rewarding experiences with IMs has been in a graduate course at the University of Toronto where user acceptance was very high.

7. STANDARDIZATION OF INTEGRATED MODELS

7.1 STANDARDIZATION IN CANADA

Workshop participants showed no enthusiasm for standardization of one or a very few Canadian IMs. As indicated schematically in Fig. 1, there is an array of possible IMs, one for each type of receptor, with quite different add-on stresses in each case. The conclusion, therefore, is that standardization of models and modules would not be desirable at present. The current diversity of models should, in fact, lead to improved IMs in the next decade.

7.2 CANADA-U.S. MODEL COMPATIBILITY

For research applications, there is no need for Canada-U.S. model compatibility. A diversity of approaches will provide a range of testable hypotheses that will lead to improved understanding of the biogeophysical and socioeconomic factors involved.

For policy applications, it would, of course, be desirable if bilateral negotiations could be based on similar ideas on the consequences of various emission reduction strategies. Thus, a single comprehensive decision support tool like RAINS would be helpful, although some Workshop participants were dubious that such a goal could be achieved.

8. INTEGRATED MODELS OF ACIDIFICATION IN THE CONTEXT OF OTHER ENVIRONMENTAL ISSUES

Acidification is only one of an array of environmental issues on the political agenda in Canada. So it is important to examine inter-relations.

1. As suggested in Fig. 1, sensitive receptors are stressed not only by acidic deposition but also by other processes. Forests, for example, can be adversely affected by acidic deposition, ozone episodes, insect infestation, poor forest management, and, over the long-term, climate change. Thus, a policy designed to restore the quality of Canada's forests based solely on simulations derived from an IM of acidic deposition would be inadvisable.

2. The environment contains important feedbacks amongst systems that are often treated separately. In the case of acidification and climate change, for example, the wind and precipitation climatologies prevailing over the last 30 years are not likely to be the same in the next 30 to 50 years, and this might change the source-receptor relations used in the IMs of acidic deposition. In this example, it is important that an evaluation be carried out on the robustness of IMs to such changes. It should also be mentioned that climate change is expected to be a continuing process so that policy adjustments made in one decade may be inappropriate in the next (Rind et al. 1988).

3. With respect to cost-of-control measures to reduce acidic deposition, the possibility exists that some of the measures would be helpful in mitigating the effects of other kinds of stresses (e.g. ozone episodes) on the environment. Cost-of-control modules should, therefore, include estimates of the benefits of such cost-sharing measures.

Although modellers should be mindful of the range of stresses that may affect sensitive receptors, priority should be given to the design of IMs that assume that acidic deposition is the only stressor.

9. RECOMMENDATIONS

The following recommendations were made by the participants of the Toronto Workshop:

1. Windows of opportunity: The environmental modelling community needs information on windows of opportunity that may occur in the next decade. One way to obtain this information is for modellers, scientists and policy people to meet periodically in a "round table" mode to seek to identify promising windows. Without such guidance, modellers may be unable to deliver their products in a timely fashion, although they may perhaps contribute to meeting future user needs. Here it should be noted

that development and evaluation of a complex IM requires considerable pre-planning as well as a development phase of at least a year.

Workshop participants suggested a first list of environmental windows of opportunity. These are given in Table 1, and it is interesting to note the similarities as well as the discrepancies in the views of the two discussion groups. Table 1 has been included not only to provide guidance on environmental windows of opportunity in Canada but also to indicate the need for further consideration of this important question.

Table 1 Suggested windows of opportunity for environmental models, as reported by two discussion groups at the Toronto Workshop on IMs of acidic deposition

Environmental Issue	Discussion Group 1	Discussion Group 2*
Climate Warming	1990	1990/1993
SO_2	1992/1993	1994
NO_x	1996	1990
Ozone	Dependent on NO_x	--
VOC	--	1990/1992
Great Lakes 1993 negotiations	1990	--

* Discussion Group 2 felt that IMs should also be developed in response to issues related to toxic substances and to general transboundary air pollution between Canada and the United States, but gave no time horizons.

2. Interdisciplinary dialogue: There is need for improved communications amongst people building and using environmental models. Topics that require special attention are data needs, linkage definition and module compatibility.

3. Model performance: As already emphasized in Section 5.2, there is an urgent need to test the performance of integrated models containing several modules, particularly when feedbacks are included.

4. Model credibility: Modellers should pay more attention to the issue of model credibility, which traditionally has not been of particular concern to them. Better documentation of evaluations and sensitivity tests might help, as well as greater attention to the attractiveness and easy interpretation of graphical displays. Another way to help achieve credibility is to involve users in model design and development.

5. Model standardization: There is no great need for standardization of one or a very few Canadian IMs. The present diversity of approaches may be desirable.

6. Integration across environmental issues: Increased efforts should be made to achieve integration across environmental issues, e.g. through simultaneous assessments of control strategies for several pollutants.

7. Organizational changes: In order to implement the above recommendations, some improvements in current organizational practices are desirable.

The following options are suggested:

(a) Creation of a working group with membership drawn from participants of the Toronto Working Group, possibly reporting to RMCC[4], and perhaps broadened to include specialists involved in other environmental issues where IMs would be helpful.

(b) Creation of a NAPAP-type[5] integrated assessment framework. This would encourage inter-agency cooperation in the development of modules that were compatible with one another.

(c) Creation of an IM unit at one of the Canadian Universities, e.g. the University of Waterloo where the socio-economic model of Statistics Canada has recently been installed. Such a unit might help in overcoming "turf" problems, although some participants at the Toronto Workshop felt that this might be counter-productive to the encouragement of inter-agency cooperation.

(d) Creation of a combination of all of the above through a consortium of government, academia and the private sector.

8. Immediate follow-up: At the final plenary of the Toronto Workshop, the recommendation was made that some of the participants should prepare a funding proposal for further development of IMs. That subgroup should be sponsored by RMCC, and one of its tasks should be to decide whether follow-up work should be carried out at a single centre such as that at the University of Waterloo, or should be distributed amongst a number of existing acidic deposition research groups and centres.

A further suggestion was that the proceedings of the Toronto Workshop should be brought to the attention of the Director of NAPAP. Follow-up informal discussion between RMSS and NAPAP and possibly a Canada-U.S. Workshop might also be desirable.

10. REFERENCES

Alcamo, J. and J. Bartnicki. 1987. A framework for error analysis of a long-range transport model with emphasis on parameter uncertainty. Atm. Environ., 21:2121-2131.

Alcamo, J., M. Amann, J.P. Hettelingh, M. Holmberg, L. Hordijk, J. Kämäri, L. Kauppi, P. Kauppi, G. Kornai and A. Mäkelä. 1987. Acidification in Europe: a simulation model for evaluating control strategies. Ambio, 16:232-245.

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[4] RMCC is the Research and Monitoring Coordinating Committee of the Canadian Committee for the Long-Range Transport of Air Pollutants (LRTAP). See Appendix 5 for an organization chart.

[5] NAPAP is the National Acid Precipitation Assessment Program in the United States.

Bangay, G.E. and C. Riordan. 1983. Work Group I, Impact Assessment. Final Report, U.S.-Canada Memorandum of Intent on Transboundary Air Pollution, Section 3, EPA (Washington) and AES (Downsview, Canada), pp. 1-180.

Clark, T.L., E.C. Voldner, R.L. Dennis, S.K. Seilkop, M. Alvo and M.P. Olson. 1989. The evaluation of long-term sulphur deposition models. Atm. Environ., 23:2267-2288.

Eliassen, A. and J. Saltbones. 1983. Modelling of long-range transport of sulphur over Europe: a two-year model run and some model experiments. Atm. Environ., 17:1457-1473.

Ellis, J.H., E.A. McBean and G.J. Farquhar. 1985. Chance-constrained/ stochastic linear programming model for acid rain abatement. I. Complete collinearity and noncollinearity. Atm. Environ., 19:925-937.

Ellis, J.H., E.A. McBean and G.J. Farquhar. 1986. Chance-constrained stochastic linear programming model for acid rain abatement. II. Limited collinearity. Atm. Environ., 20:501-511.

Frenkiel, F. and D.W. Goodall (Eds.) 1978. Simulation Modelling of Environmental Processes. Scope 9, John Wiley and Sons, Chichester, New York, Toronto, 112 pp.

Jones, M.L., C.K. Minns, D.R. Marmorek and F.C. Elder. 1989. Assessing the potential extent of damage to inland lakes in Eastern Canada due to acidic deposition: II. Application of the regional model. Subm. to Can. J. Fish and Aquat. Sci.

Jones, M.L. and C. Wedeles. 1989. Developing a regional model of acidification effects on waterfowl. ESSA, 66 Isabella Street, Toronto, 51 pp.

Lam, D.C.L., A.S. Fraser and A.G. Bobba. 1987. Simulation and analysis of watershed acidification. In: "Systems Analysis in Water Quality Management", (Ed.) M.B. Beck. Pergamon Press, Oxford, pp. 85-96.

Lam, D.C.L., A.S. Fraser, D.A. Swayne, J. Storey and I. Wong. 1988. Regional analysis of watershed acidification using the expert system approach. Environ. Software, 3:127-134.

Lam, D.C.L., G. Howell, D.A. Swayne, A.S. Fraser, J. Storey and I. Wong. 1989. A knowledge-based approach to regional acidification modelling: a case study of New Brunswick, Canada. In: "Proc. Aulanko Conf. on Acidification Modelling", (Ed.) J. Kämäri, (in press).

Loucks, D.P., J.R. Stedinger and U. Shamir. 1985. Modelling water resource systems: issues and experiences. Civil Eng. Systems, 2:223-231.

Marmorek, D.R., M.L. Jones, C.K. Minns and F.C. Elder. 1989. Assessing the potential extent of damage to inland lakes in Eastern Canada due to acidic deposition. I. Development and evaluation of a simple "site" model. Subm. to Can. J. Fish and Aquat. Sci.

McBean, E.A. 1987. Developing management positions for acidic emission reduction negotiations. In: "Systems Analysis in Water Quality Management", (Ed.) M.B. Beck. A chapter in Water Poll. Control Symposium Proceedings, pp. 51-59.

Minns, C.K., J.E. Moore, D.W. Schindler and M.L. Jones. 1989. Assessing the potential extent of damage to inland lakes in eastern Canada due to acidic deposition. IV. Predicted impacts on species richness in seven groups of aquatic biota. (MS in draft form.)

Munn, R.E., J. Alcamo and V. Federov. 1988. Evaluating the performance of air quality models in a policy framework. Air Pollution Modelling and its Application, (Ed.) H. van Dop. Plenum Press, New York and London, Vol. 11:237-258.

Olsthoorn, T.N., J.A. van Jaarsveld, J.M. Knoop, N.D. van Egmond, J.H.C. Mülschlegel and W. van Duijvenbooden. 1989. Integrated modelling in The Netherlands. In: Proc. Riso Int. Conf. on Environ. Models: Emissions and Consequences, Elsevier Sci. Pub. S.V., Amsterdam (in press).

Rind, D., A. Rosenzweig and C. Rosenzweig. 1988. Modelling the future: a joint venture. Nature, 334:483-486.

Rubin, E.S. 1989. Characterizing uncertainty in integrated environmental models. In: Proc. Riso Int. Conf. on Environ. Models: Emissions and Consequences", Elsevier Sci. Pub. S.V., Amsterdam (in press).

Schiermeier, F.A. and P.K. Misra. 1983. US-Canada Memorandum of Intent on Transboundary Air Pollution, Rep. ZF-M, EPA, Washington and AES, Downsview, Canada.

Shaw, R.W. 1986. A proposed strategy for reducing sulphate deposition in North America. II. Methodology for minimizing costs. Atm. Environ., 20:201-206.

Streets, D. 1988. A review of acid rain models for Europe. Task Force on Integrated Assessment Modelling, UNECE, May 6, 1988.

Streets, D.G. 1989. Integrated assessment: missing link in the acid rain debate. Environ. Management, 13:393-399.

Venkatram, A., B.E. Ley and S.Y. Wong. 1982. A statistical model to estimate long-term concentrations of pollutants associated with long-range transport. Atm. Environ., 16:249-257.

Voldner, E.C., M.P. Olson, T.L. Clark, R.L. Dennis, M. Alvo and S. Seilkop. 1988. The international sulphur deposition model evaluation: a summary. In: "Air Pollution Modelling and its Applications, (Ed.) H.V. Dop. NATO CCMS, Plenum Press, New York, pp. 305-320.

Young, J.W.S. and R.W. Shaw. 1986. A proposed strategy for reducing sulphate deposition in North America. I. Methodology for Minimizing sulphur removal. Atm. Environ., 20:189-199.

APPENDIX 1

WORKSHOP ON INTEGRATED MODELS OF ACIDIC DEPOSITION

PROGRAM

TUESDAY APRIL 25

Session 1: 9:30 a.m. - 12:30 p.m.

Chairman: Ted Munn

1. Opening remarks: Ted Munn and Doug Whelpdale

2. Overview Paper: Integrated Models of Acidic Deposition - Modeller Expectations and User Acceptance:

   (a) Conceptual framework - Ted Munn
   (b) The North American experience - Doug Whelpdale and Tom Brydges

3. The Case for Integrated Models in Canadian Environmental Decision-Making - Phil Cohen

4. The Demand for Integrated Models in the Context of Policy Decisions Relating to Acidic Deposition - Alex Manson

5. The European Experience - Rod Shaw

6. The Use of Integrated Models of Acidic Deposition in the United States - Marylynn Placet

12:30 - 2:00 p.m. Buffet lunch (at the Institute)

Session 2: 2:00 - 5:00 p.m.

Chairman: Phil Cohen

The Use of Integrated Models of Acidic Deposition in Canada - presentations of 15 minutes each by:

- David Lam
- Ken Minns
- Rod Shaw
- Ed McBean
- John McEwen
- David Marmorek

5:30 p.m. Wine and Cheese Reception (at the Institute)

WEDNESDAY APRIL 26

Session 3: 9:30 a.m. - 12:30 p.m.

Discussion groups

Topic for both groups: Integrated Models of Acidic Deposition - the Current Position and Recommended Future Direction.

GROUP 1 Chairman: Doug Whelpdale - Rapporteur: Dean Jeffries

GROUP 2 Chairman: John Hollins - Rapporteur: Sherri Watson

12:30 - 2:00 p.m. Buffet lunch (at the Institute)

2:00 - 4:00 p.m. Closing plenary session

Chairman: Tom Brydges

Guidelines for Chairmen and Rapporteurs
of the Two Discussion Groups

Discussion Topics

1. What are the needs for integrated models in Canada?

2. To satisfy these needs, what model components and field data are required? Are the field data currently available?

3. Has model performance been demonstrated? (statistical tests? sensitivity analyses? scientific judgement/consensus?)

4. Have the models been accepted by the intended users? If not, why not?

5. What is the possibility of standardization to produce only one or a few integrated models?

6. What needs to be done to improve the present situation? Give specific recommendations.

7. How should these recommendations be implemented?

APPENDIX 2

WORKSHOP ON INTEGRATED MODELS OF ACIDIC DEPOSITION

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APPENDIX 3

INTEGRATED MODELS OF ACIDIC DEPOSITION: MODELLER EXPECTATIONS AND USER ACCEPTANCE

R. E. Munn[1], T. Brydges[2] and D. M. Whelpdale[1,2]

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1. INTRODUCTION

A Workshop on Integrated Models of Acidic Deposition was held at the University of Toronto 25-26 April, 1989. This paper and the parallel one by Cohen (1990) provided a framework for Workshop discussions.

Source-to-receptor integrated models of acidic deposition involve many biogeochemical elements and processes, covering a range of space and time scales. In some cases, these models (often in simplified form) are the central core of a larger model which includes socioeconomic factors, namely:

1. a front-end cost-of-emission-control model (for cost-effectiveness assessments); and/or
2. a rear-end socioeconomic damage model (for cost-benefit and cost-of-doing-nothing assessments).

Even with easily understandable graphics, however, it may be difficult to persuade potential clients to use such a complex model as a tool in helping to reach decisions on emission control and associated environmental research strategies. The problem of user acceptance of integrated models of acidic deposition is the subject of this paper.

2. POTENTIAL USERS OF INTEGRATED MODELS

We must emphasize at the outset that whenever a model of acidic deposition is constructed, the creators usually have a particular application in mind, and their model conceptualization may have been constrained by the limited data available. In most cases, the resulting model represents a practical compromise that is quite suitable for the purpose(s) for which it was developed. Difficulties arise only if the model is put to other uses or is transposed to different space-time scales and resolutions.

In general terms, integrated models are designed to meet one of the following objectives:

1. To describe an environmental field (interpolation models);
2. To explain the characteristics of an environmental field (diagnostic models);
3. To predict an environmental field (prognostic models);
4. To manage the future behaviour of an environmental field (simulation models*);
5. To help in the design of monitoring networks;
6. To provide a framework for determining research programs and priorities;
7. To provide a teaching aid in the context of interdisciplinary research studies.

This is quite a long list, and we think it unrealistic to believe that a single integrated model of acidic deposition could be of universal applicability.

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*Simon (1988) uses the term "prescription" to define this type of model

3. HOW CAN MODEL PERFORMANCE BE ASSESSED?

Model outputs are usually maximum likelihood estimates for given inputs and assumptions inherent in the model structure. However, model outputs ought also to include some indication of uncertainty, e.g., 95% confidence levels. This seems only reasonable to expect, if a user is to decide whether a model output is sufficiently accurate to meet his needs. In practice, the evaluation of model uncertainty is very difficult (Munn et al. 1988). The problem is particularly severe when the model is used to simulate conditions quite beyond the range of human experience, as in the case of climate warming. In such cases, it is difficult to decide even whether one model is performing "better" than another.

Table 1 lists appropriate types of tests of model performance for particular user needs. The Table is to be considered as indicative only, there being overlaps amongst the various categories.

Table 1. Model performance tests appropriate for particular user needs

User Need	Performance Test
Description/interpolation	Statistical
Explanation (diagnostic models)	Scientific judgement
Prediction (prognostic models)	Statistical
Policy-making (comparison of alternative strategies) (simulation or gaming models)	sensitivity analysis
Design of monitoring networks	Statistical
Development of integrated research program	Scientific judgement/ sensitivity analysis
Teaching aid	Scientific judgement

*Test data may not be available to cover the range of input conditions for any or all of the alternatives

A large body of literature exists on statistical tests of model performance. In many cases, model predictions are compared with observations using, for example, root-mean-square differences as an indicator of performance. However, several difficulties are encountered. For example:

1. Pairwise comparisons between predictions and observations of long-range transport may be poor because of a small but persistent error in wind direction. If rotation of the axes (by 30 degrees, say) provides a much better fit, how should model performance be assessed?

2. Pairwise comparisons between predictions and observations may be good in general but the model may perform badly in the uppermost 2-5% of the frequency distributions of concentrations. If the extremes are important in policy analyses, how should such a model be assessed?

These examples suggest that pattern recognition may be an important consideration in the design of performance tests. Thus for example, Clark et al. (1987) began with the array of indicators given in Table 2 in their comparison of the performance of 11 long-range sulphur deposition models in North America. See also Voldner et al. (1988).

Table 2. Measures used to assess the performance of 11 long-range sulphur deposition models in North America (Clark et al. 1987).

I. Replication of Spatial Pattern		
A. Magnitude	1.	Area of significant differences*
	2.	Difference between the medians
	3.	Difference between the dispersions
	4.	Bias in the high deposition region
	5.	Bias in the low deposition region
	6.	Mean squared error
B. Position	1.	Distance between the centroids*
	2.	Difference in the orientation of the major axes*
	3.	Distance of the predicted pattern shift to achieve the maximum spatial correlation
C. Shape	1.	Maximum spatial correlation resulting from predicted pattern shifting and rotation
	2.	Spatial correlation without predicted pattern shifting
II. Maxima		
A. Location: Distance of separation*		
B. Magnitude: Absolute difference*		
III. Replication of Temporal Pattern		
Differences in seasonal contributions to the annual total*		
IV. Concurrence of Aggregated Seasonal and Annual Results		
Relative differences between the aggregated seasonal and annual predictions.		

*Primary model performance measures subsequently used to cluster the models according to performance.

The second type of model performance evaluation is scientific judgement. Some of the questions to be asked in this kind of assessment are:

1. Are the model equations dimensionally correct?
2. Is the model scientifically sound?
3. Is the model appropriate for the system? (scale, geometry, physical/chemical processes)
4. Are the available data of sufficient quality, quantity, representativeness and spatial coverage for unbiased model evaluations. For example, predicted values may be spatial averages whereas observations are point values.
5. Are model predictions likely to be acceptable outside the range of conditions used for model development and testing?

The third kind of model performance test is sensitivity analysis, in which model inputs are changed by fixed amounts or are replaced by values drawn randomly from probability distributions (Alcamo 1988; Munn et al. 1988). For example, sensitivity analysis provides a test of the robustness of an environmental management policy, to uncertainties in our understanding of biogeochemical and socioeconomic processes. The choice of an optimal strategy for reducing North American sulphur emissions would clearly depend on the wind climatology used. How robust would this strategy be to a major change in the continental wind fields due to greenhouse-gas climate warming over the next 50 years? Sensitivity analysis is a way of answering this question.

A final point to be made with respect to performance testing is that the quality of a model as judged by a modeller (e.g., low root-mean-square error between predictions and observations) may not correspond to its ecological, sociological or economic significance. As pointed out by Munn et al. (1988), the arguments and assumptions used to make judgements on model significance should be made explicit.

4. USER ACCEPTANCE OF INTEGRATED MODELS OF ACIDIC DEPOSITION

4.1 SOME GENERAL PROBLEMS WITH USER ACCEPTANCE

Particularly in the case of "big" integrated models with time scales extending decades into the future, user acceptance is often difficult to achieve. In fact many complex models have had little impact on policy people (Frenkiel and Goodall 1978) although the cost of development may be justified through their use as research and teaching tools, or as a means of changing public perceptions. As examples of the latter, the limits-to-growth models of the early 1970's drew public attention to the need for conservation of renewable resources, while the nuclear winter models of the early 1980's had a favourable impact on global nuclear disarmament negotiations, despite continuing scientific debate about the models themselves.

Some of the reasons that user acceptance is difficult to achieve are:

1. The modeller has been unwilling to specify the uncertainty in his model outputs. See Section 3 above.

2. Model assumptions and linkages between environmental compartments have not been made sufficiently transparent. For example, can the consequences be quickly revealed on a computer screen, of modifying one of the assumptions in the model?

3. The model is not sufficiently user friendly. For example, tabular and spatial displays of model outputs may be too technical for a Minister of the Environment or his senior policy advisors.

4. The issue at hand is not sufficiently well defined. In such cases, modellers and policy people may not share a common understanding of the problem (Frenkiel and Goodall 1978).

5. The model provides too much information, making it difficult for a user to evaluate alternatives.

6. The model being used is one that was developed for a more general purpose or sometimes even for quite a different reason. The cost of developing a more specifically user-oriented model might be considered to be too costly. In the long run, however, the process of establishing trust between the modeller and the user would otherwise be damaged.

7. Even when the model being used does not suffer from the above-mentioned short-comings, the model still may not be fully accepted if it is merely used to feed results or policy alternatives up the bureaucratic chain to the highest levels of decision-making. A far better approach is to use the model in a gaming or "policy exercise" framework (Brewer 1986; Toth 1988) in which all the "players" are present. This is very difficult to achieve but the results can be very rewarding (Stigliani et al. 1989), particularly when the issues are poorly defined.

8. In some cases, of course, political considerations dominate. For example, of the many land-use models built in the 1960's and 1970's, few survive. This is because land-use planning is very political, involving a number of levels of government. The stake-holders have differing value systems, priorities and biases. This means that the main issue is conflict resolution in the presence of uncertainty. But this is a situation for which simulation models and policy exercises are particularly suited, and should be applied.

For those who distrust simulation models, the alternative is to use incremental management strategies. As pointed out by Rind et al. (1988), environmental change is a continuing phenomenon so that socioeconomic adjustments made in one decade may be inappropriate for the next. For management decisions that commit society several decades ahead, e.g., the damming of a river or the construction of a power station, this approach to environmental management is very wrong indeed.

4.2 THE CANADIAN EXPERIENCE

The application of integrated models for acid deposition has been somewhat erratic in Canada during the past decade. This limited use has resulted from a combination of the following factors:

1. the limited availability of Canadian integrated models;
2. the absence of a visible, independent agency to "champion" their use (cf. IIASA in Europe);
3. scepticism of scientists and science managers; and
4. the short time-scale of political decision-making.

The following example applications attempt to provide some background along with an indication of the current degree of acceptance which these models enjoy in Canada.

4.2.1 Integrated Modelling in the LRTAP Scientific Program

Within the federal LRTAP program in Canada during the past decade, the appropriate use of integrated models has been a perennial question. At the beginning of the program back in the late 1970's, recommendations were made that an integrated model be used to help design the embryonic LRTAP program. The model was to accomplish two things:

1. ensure that scientists from different disciplines would discuss and understand each others' needs; and
2. identify problem areas or gaps in the sequence of scientific steps necessary to meet the program's goals.

These would have contributed to the "integrated" nature of the program. Unfortunately, the reactions of scientists and managers responsible for the program at that time were that this was not a "scientific" approach and that we didn't know enough to link together the various disciplines in a single model. The integrated modelling approach was new then and there was not an adequate understanding of the uses to which such a modelling approach could be put.

As will be seen in some of the following examples, a number of participants in the program realized the value of the approach and made good use of it for a number of applications over the years. However, even now when we are nearing an important decision point is the LRTAP program, and an integrated assessment is required, it appears that some of the scepticism remains, although the reasons given by the doubters have changed. In the early days, the argument was advanced that insufficient knowledge and field data existed to design and test a model. This argument is flawed: integrated models are particularly useful in the early stage of a study, providing guidance in the design of monitoring systems. Today, integrated models are not being used in part because of the concern that they cannot replace scientific judgement, and that they don't really "integrate" knowledge. We still seem to suffer from a fear of the unknown, and from a lack of appreciation of exactly what role these models serve! Perhaps this workshop will serve to broaden our outlook.

4.2.2 Integrated Modelling in the Design of Federal-Provincial Emission Reductions

Environmental models have been an integral and essential component of pollution control programs in Canada for decades. For example, river dissolved-oxygen models are an important component in defining sewage treatment plant effluent requirements. Models capable of predicting ground-level air concentrations around individual chimneys have been used on a routine basis for establishing emission limits.

These are examples of models that use an empirical approach, calibrated by field observations, but are supported by physical and biological theory (i.e. the dissolved-oxygen models take into account the biological consumption of oxygen as affected by temperature and the re-entrainment of oxygen from the atmosphere due to a number of physical factors). The ground-level air concentration models rely heavily on the principles of fluid mechanics.

One example of the operational use of environmental models is weather predictions. Vast amounts of meteorological information are fed to computers in real time and the computers in turn use very sophisticated meteorological models to predict likely weather conditions on a relatively small regional scale for periods of time of up to five days. Models are now being considered which will be capable of predicting weather conditions on a regional basis for up to thirty days.

The dissolved-oxygen and ground-level air concentration models focus on a small geographical area and on one, or a small number, of pollutant sources. As pollution problems have become larger, and involve multiple sources, the modelling approach required has also become more complicated. One of the first large-scale multi-source environmental problems to be tackled was eutrophication, particularly in the Great Lakes. Vollenweider (1968) published an empirical model relating phosphorus loadings to lake depth and defined a series of loading depth regimes which corresponded to eutrophic, mesotrophic and oligotrophic lakes. His model was almost entirely empirical and its application to the reduction of phosphorus loadings to control eutrophication was in large part based on his judgement since the model made similar predictions with regard to the control of nitrogen loadings. His model, which was supported by laboratory demonstrations of the effectiveness of controlling phosphorus, became the basis of large-scale control actions in the Great Lakes Basin. In this case, the degree of pollution control was not defined by the model but, in fact, was defined by the engineering and practicality of waste treatment available at the time.

The long-range transport of air pollutants, or more specifically acid rain, has added further dimensions of complication to an environmental issue. While eutrophication was a multi-source issue, it essentially affected only one medium (i.e. lakes) whereas the long-range transport of air pollutants has involved atmospheric, biota, soil, and lake processes. Acid rain has the added complication that the sources of the pollution are not as directly linked to the receptors as in the case of effluent pipes discharging to lakes or rivers. Therefore, it is not surprising that the modelling approaches to long-range transport of air pollution have also taken another leap forward in sophistication and complexity.

In the mid-1970's, Canada recognized the acidification problem in surface waters, based on field observations, and drawing heavily on Scandinavian

experience. In the early 1980's, Canada and the United States both recognized that an acidification problem existed and committees were established to determine a level of reduction that would be required to protect the environment. The approach taken was essentially the one used by Vollenweider. In the case of acidification, environmental data from eastern North America were assembled and it was noted that all areas receiving 20 kg/ha/year or more of wet sulphate had reported some evidence of surface water acidification damage. The field observations were supported by theory and models. The final report (MOI 1983) pointed out that there were no observations of serious surface waters acidification for areas receiving 17 kg/ha/year or less. The 20 kg/ha/year target loading was accepted within the Canadian political system. Since the maximum deposition being observed was approximately 40 kg/ha/year of wet sulphate, the decision was reached to reduce emissions by 50% and thereby reduce the deposition by 50%.

In 1984, the seven eastern Canadian provinces in association with the federal government agreed to reduce emissions from the 1980 regulated value of about 4.6 M tonnes/year by 50% by the year 1994. Having reached this political decision, based on the judgement of the scientific community, the task was then to design a specific control program.

The eastern Canadian provinces agreed to develop the provincial reduction allocations in consultation with the federal government. This was to be followed by the specific industrial allocations within each province. In 1985, the federal government announced a $150 M fund to be matched equally by the provinces to provide support in cases of demonstrated industrial need.

The provinces considered a number of options for allocating the required emission reductions such as per capita emissions, emission reductions on an areal basis and reductions according to gross provincial product. Each of these was rejected in favour of an environmentally driven least-cost approach.

The provinces used the screening model developed by Ellis et al (1986). The model considered individual sources greater than 19,000 tonnes/year of which there were 219 in the United States and 16 in Canada. Sources smaller than 19,000 tonnes/year were regarded as not amenable to controls and were grouped as area sources; a total of 83 such areas were included in the model calculations. Control cost functions were included for each industry when available and when specific information was not available, generic control cost functions were used. This was the case for many industries, particularly power plants. The model included a source-receptor atmospheric model, which calculated the deposition at 20 sensitive receptor areas, 16 in Canada and 4 in the United States. For each analysis performed, there were 235 transfer coefficients for the industries and 83 transfer coefficients for the area sources which had been summed for each of the 20 receptor areas to obtain the total deposition levels resulting from various control scenarios. The model was then used to calculate the various options of obtaining any particular deposition value in any particular receptor area. In general, the model was run to provide the least-cost control so that no area would receive greater than 20 kg/ha of wet sulphate deposition.

The three industrial sources most amenable to controls were the non-ferrous smelters, thermogenerating stations and oil refineries. The cost of removing a tonne of SO_2 from the effluents increased in the same order. Consequently, application of the screening model determined that the least-cost controls would

be heavily oriented towards the smelters at Sudbury and Noranda and little or no reduction would be required by the oil refineries. This approach was further supported by the fact that the large non-ferrous smelters were located in close proximity to the sensitive areas. The model served as an essential guide to the interprovincial negotiating process. However, it must be emphasized that the decision to make the reductions had already been reached, based on the analysis of other environmental information. Agreement on interprovincial allocations was reached in early 1985; all 7 eastern Canadian provinces are currently at varying stages of implementing their commitments. While the model played a very important role in guiding the negotiating process, it must be recognized that many other political, engineering and social factors entered into the final control program decisions.

4.2.3 Integrated Models as a Teaching Aid

One of the most rewarding experiences with integrated models has been their use in a graduate course given by Mike Jones and helpers at the Institute for Environmental Studies at the University of Toronto over the past several years. The course has been entitled "Man-Environment Theory II, Adaptive Environmental Assessment and Management" (AEAM), or simply, simulation modelling. The course has been given in a modified AEAM workshop format, with students taking roles of the various stake-holders, and being given responsibility for designing model components, gathering data and analysing results. Two recent applications have been examining the socio-economic impacts in the Great Lakes Basin (Lake Simcoe in particular) of climate change resulting from CO_2 doubling scenario, and examining the ecosystem impacts in eastern Canada of three SO_2 emission scenarios.

User acceptance in this application has been very high, both on the part of the instructors and the students. The development and application of the model by the students achieved the following:

1. interaction among the students;

2. an ability to work together in groups;

3. an appreciation of others' needs and points of view;

4. an understanding of uncertainty in individual components, and how it propagates through a system of several components;

5. a demonstration of the "interconnectedness" of parts of an issue (how if one tweaks the web at one point, it may respond at another completely unexpected spot); and

6. a demonstration of the value of tackling a real-life issue in its entirety, even if in a simplified way.

The development and application of an integrated model in this type of forum provides a nice blend of qualitative and quantitative approaches, a combination of natural and social science perspectives, and a broad appreciation of a current issue. An additional benefit, of course, is that students quickly graduate and become professionals, who appreciate the value of, and are favourably disposed towards integrated models.

5. SOME GENERAL CONCLUSIONS AND OPEN QUESTIONS

People from many biogeochemical and socioeconomic fields have important roles to play in the assessment and management of acidic deposition. Unfortunately each discipline involved has its own agenda, and non-specialists often have difficulty in getting an overview of the many issues involved. This is true not only for politicians and their senior policy advisors but also for program managers and sometimes even for the scientists themselves. Yet an overview is essential to understand the complex processes and interactions taking place, to assign research priorities and to develop appropriate control strategies. Integrated models can help in providing an overview, and their use should be encouraged. But models are designed explicitly or implicitly to perform certain tasks, and the application of an integrated model out of context to meet other goals may not be advisable.

Here it should also be emphasized that members of a model-building team often approach the process in terms of the outputs that they can provide to other members of the team. A more productive approach would be to specify the inputs that will be needed from other members of the team. Admittedly the input requests may prove to be unreasonable or scientifically inadmissible. However, a basis for subsequent dialogue will have been laid.

This Workshop on Integrated Models of Acidic Deposition should perhaps have taken place several years ago. Nevertheless, the subject matter is still very important, and the authors hope that it will provide guidance on the following questions:

1. What are the needs for integrated models in Canada?

2. To satisfy these needs, what model components and field data are required? Are the field data currently available?

3. Has model performance been demonstrated? (statistical tests? sensitivity analyses? scientific judgement/consensus?)

4. Have the models been accepted by the intended users? If not, why not?

5. What is the possibility of standardization to produce only one or a few integrated models?

6. What needs to be done to improve the present situation? Give specific recommendations.

7. How should these recommendations be implemented?

Because North America is a common "airshed" for acidic deposition, this Workshop may need to be followed by bilateral discussions or perhaps another Workshop cosponsored by NAPAP. In the European policy arena for acidic deposition, an integrated model RAINS (Alcamo et al. 1987) is providing valuable inputs to discussions of appropriate national and ECE bodies. Could a RAINS-type model meet the needs of scientists and politicians in both Canada and the United States?

LITERATURE CITED

Alcamo, J. 1988. Uncertainty of forecasted sulfur deposition due to uncertain spatial distribution of SO_2 emissions. Air Pollution Modelling and its Application, 11:283-291, (Ed.) H. van Dop. Plenum Press, New York and London.

Alcamo, J., M. Amann, J.P. Hettelingh, M. Holmberg, L. Hordijk, J. Kamari, L. Kauppi, P. Kauppi, G. Kornai and A. Makela. 1987. Acidification in Europe: a simulation model for evaluating control strategies. Ambio 16: 232-245.

Brewer, G. 1986. Methods for synthesis: policy exercises. In: Sustainable Development of the Biosphere, (Eds.) W.C. Clark and R.E. Munn, pp. 455-473.

Cohen, P. 1990. The case for integrated models in Canadian environmental decision making. See Appendix 4, this Monograph.

Ellis, J.H., E.A. McBean and G.J. Farquhar. 1986. Chance-constrained/ stochastic linear programming model for acid rain abatement. II. Limited collinearity. Atm. Environ. 20: 501-511.

Frenkiel, F.N. and D.W. Goodall (Eds.) 1978. Simulation Modelling of Environmental Processes, SCOPE 9, John Wiley and Sons, Chichester, New York, Toronto, 112 pp.

MOI. 1983. United States-Canada Memorandum of Intent on Transboundary Air Pollution: Impact Assessment, WG 1, Final Report, Jan. 1983.

Munn, R.E., J. Alcamo and V. Fedorov. 1988. Evaluating the performance of air quality models in a policy framework, Air Pollution Modelling and its Application, 11:237-258. (Ed.) H. van Dop. Plenum Press, New York and London

Rind, D., A. Rosenzweig and C. Rosenzweig. 1988. Modelling the future: a joint venture. Nature 334:483-486.

Simon, H.A. 1988. Prediction and prescription in system modelling, unpublished manuscript presented at IIASA Conference (June 1988), 13 pp.

Stigliani, W.M., F.M. Brouwer, R.E. Munn, R.W. Shaw and M. Antonofsky. 1989. Future environments for Europe: some implications of alternative development paths, Sci. Total Environ., 80:1-102.

Toth, F. 1988. Practising the future, Part 2: lessons from the first experiments with policy exercises. IIASA WP-88-12, 31 pp.

Voldner, E.C., M.P. Olson, T.L. Clark, R.L. Dennis, M. Alvo and S. Seilkop. 1988. The international sulfur deposition model evaluation: a summary. Air Pollution Modeling and its Application, 11:305-320. (Ed.) H. van Dop. Plenum Press, New York and London.

Vollenweider, R.A. 1968. Studies on management of water. The scientific basis of eutrophication in lakes and rivers with particular reference to phosphorus and nitrogen as factors in eutrophication. In OECD, DAES/CSI/68-27.

APPENDIX 4

THE CASE FOR INTEGRATED ATMOSPHERIC MODELS IN CANADIAN ENVIRONMENTAL DECISION-MAKING

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EXECUTIVE SUMMARY

This paper discusses the case for integrated modelling in Canadian environmental decision-making, with respect to Long Range Transportation of Air Pollutants (LRTAP), the looming greenhouse gases problem, and associated "local" environmental issues.

The increasing complexity and severity of the LRTAP and greenhouse gases problems have resulted in a growing need for the incorporation of integrated modelling in assessing socio-economic impacts and proposed remedies. In Europe and Japan, this incorporation is already under way. While the technical know-how to develop and use these models exists in Canada and the U.S., the models have not been employed to any great extent in the decision-making process. However, with the continuing increase of environmental awareness and the evolution of American concern regarding acidic deposition, it is expected that the need for this kind of modelling support will grow in the near future.

In anticipation of this need, it is recommended that work be continued in Canada to prepare models that can be used in the LRTAP and greenhouse-gas decision making process.

In this paper it is argued that fully integrated models are not user friendly and that an international trend is building to separate the problem into a "critical load" (CL) problem (how much deposition should be permitted) and a source-receptor (SR) problem (where and by how much must deposition be cut back in order to reduce deposition to a level which is below the socially acceptable "target" load). It is argued in this paper that CL and SR problems have been essentially solved for sulphate deposition and now need to be solved for VOC's, NOx, and greenhouse gasses, within the next two to five years.

In addition it is argued that more work needs to be done in this same time frame for sulphate deposition, to provide information on what areas will not be protected when present Canadian acid rain agreements for 1994 will have been put in place.

Finally it is argued that these models can be a useful aid when it comes to planning a LRTAP research agenda.

1. INTRODUCTION

One purpose of an integrated assessment model of acidic deposition within the Canadian LRTAP process is to provide the necessary bridges between scientific research and policy analysis. In this context, a short definition of an integrated model might be "a faithful representation of the scientific processes that permits and facilitates the comparison of the effects of alternative policy options". In the early 1980s, the U.S. National Acid Precipitation Assessment Program (NAPAP) funded a study to design a conceptual integrated acid rain assessment model. As part of their work, the NAPAP assessment team constructed an information flow diagram as a conceptual framework for a fully integrated model. Figure 1 shows this structure and its six modules. We shall take this concept as a good example of integrated models.

In Europe, several integrated models are used by individual countries as well as by the OECD and the United Nations Economic Commission for Europe (ECE) to assess the impact of various emission control strategies.

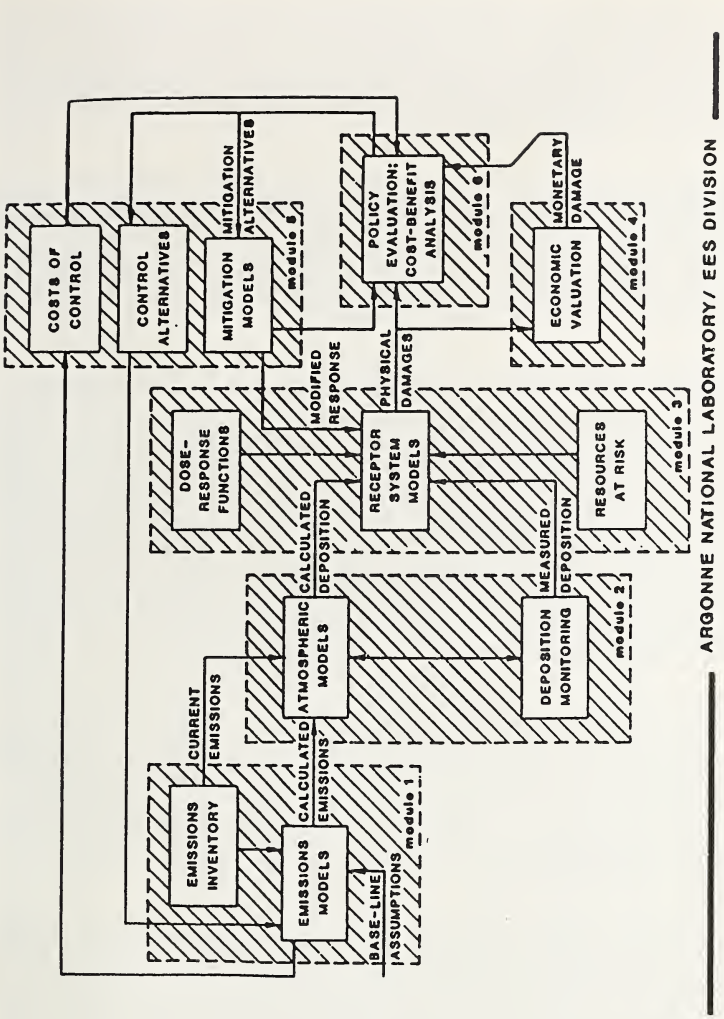


Fig. 1. An ideal integrated assessment framework
Source: Streets 1988.

In Canada there has been some use of integrated models in the past (especially during the successful 1983 federal/provincial negotiations for SO_2 controls in Eastern Canada). More recently, partly because of cost and partly because of the political stalemate within the U.S. (over acid rain), these models have not been much further developed. In the 1985 NAPAP interim assessment, it was stated that "the fully integrated NAPAP System would be available in 1989 for use in the final NAPAP assessment".

The object of this paper is to examine why and how integrated models should and can be more widely used in Canada. In Section 2 the growing demand for these models is examined. In Section 3 an overview is presented of the integrated modelling techniques that are currently available. In Section 4, a proposal is made on how better to integrate these techniques into Canadian environmental decision-making. Finally in Section 5, another potential application of integrated models is described: the setting of priorities within research budgets for studies of acidic deposition.

2. INCREASING CANADIAN NEED FOR INTEGRATED MODELS IN A POLICY FRAMEWORK

As environmental decision-making has become more a part of the political process, one of the problems that has arisen is the question of how to weigh and compare the various competing environmental/economic factors to come up with politically, environmentally, and economically acceptable solutions. One way in which this process can be aided is through the use of integrated planning models which can help decision-makers understand and compare the socio-economic impacts of possible policy options. However, in order for integrated planning models to be useful to decision makers, there must be a demand for such models as well as a supply of models whose performance has been adjudged satisfactory by the scientists, and which have been rendered sufficiently "user friendly". In this section, we elaborate on present and potential demand and in the next section look at the supply available to satisfy this demand.

One can characterize the demand for integrated planning models as either international, national, or local. Examples of local demand might be that for a model which would help find an acceptable solution for the Remedial Action Plan to clean up Hamilton Harbour. In Europe, local models are being used in Swedish towns to decide on environmentally sound plans for energy use and production. National and international models, on the other hand, deal with more aggregated areas such as a province, a nation, or a continent. National/international European models (such as the IIASA RAINS model) are beginning to be used as tools for planning environmentally and economically optimal emission reductions for both eastern and western Europe.

In Canada, in the absence of anything better, some fairly simple integrated SO_2 models were used both in acid rain negotiations with the United States and in federal/provincial negotiations. The demand was first for models that would deal with the SO_2 problem. However, as the reduction in SO_2 emissions started to occur, it was found that emissions of some other substances were important and are projected to continue to increase. As a result, the demand is changing to planning models that take into account not only SO_2 but also NO_x, VOCs, and ground-level ozone.

Also, within the next 2-5 years, the demand for these models will probably expand to include greenhouse gases. This is especially true because of the 20%

world-wide reduction in CO_2 that was called for in the 1988 Toronto Conference on the Changing Atmosphere. If properly developed, these models could be very useful in the next round of negotiations for North American emission cuts that will be necessitated by the realization that our first-round efforts were insufficient and that further cuts are needed if sustainable development is to be realizable. Thus integrated models can be used not only to look at what to do next but also to see what has not been protected by what has already been done.

Another dimension of the demand for these models is the extent to which they are "integrated". In theory one would like a user-friendly integrated model that will be capable of identifying a policy option which minimizes the aggregate socio-economic impact for a given level of economic activity. Social impact, in this general sense, could mean number of days of life lost per person (of a given age) due to a certain level of deposition. It could also, for example, be measured by the extent of wildlife diversity lost in a given region.

The problem with integration at this level is that often the appropriate models are not available and, even if they are, the output is too complex for the decision-maker to interpret and use. Thus there must be a balance between degree of integration of a model and its ease of use. In the past, modellers have attempted to deal with this problem by building a single integrated model which they tried to tailor to fit all of the above needs. The result of these heroic attempts has been that many "integrated" modelling attempts were not finished in time to be useful and the sub-parts of the models that have been built produced results that the politicians found difficult to use. As a result of this lack of demand for their work, the modelling community has taken steps to break up their models into parts (or sub-modules - that have begun to make them more user friendly. The first step has been taken to develop fairly detailed intra-national models (i.e. the MARKAL models) and a less detailed international models (i.e. the RAINS model). The international models are less technology specific and are used to develop overall environmentally sound strategies. The national models are used to develop an efficient and politically acceptable strategy that fits within international requirements.

The other aspect that appears to have evolved recently, as a result of demand from policy users of the models, is an inclination to break up the international integrated modelling effort into two parts. The first is made up of critical load modules which are used to help decide the maximum deposition of a given loading that a particular geographical location can sustain without hampering the natural productivity of the region. Thus, for example, it might be decided that the critical load for acid deposition on a particular lake is the maximum acid loading that the lake can sustain without "dying". The roll-up of these "critical loads" is then used as a basis for political negotiations to decide on a less strict, but politically feasible "target load". In the past, Canada has chosen to have a target load for all of Eastern Canada of 20 kg/ha of wet sulphate deposition. These target loads are then used in the second part of the modelling effort to decide what is technically the best way to achieve the "target load". Obviously, there is a non-automatic politically driven feed-back loop that affects the choice of target load for the input to the second part of the model. Thus Canada's modelling effort, and for that matter international modelling efforts are no longer focussed on the construction of one big model but rather on the design of several smaller, compatible, and easier-to-use models.

3. AVAILABLE INTEGRATED MODELLING TECHNIQUES

Table 1 lists the major integrated models that are presently available or that will soon be available. References for these models are found at the end of the paper. The models generally fall into three classes; integrated international models, integrated national models, and integrated local models. The integrated international models can be further broken up into critical load (CL) models and source-receptor (SR) transport models.

The major international integrated model for Europe is IIASA's RAINS model. This model contains both CL modules (for forest soils and lakes) as well as a SR module. For North America, no model of this calibre and level of detail currently exists nor for that matter does an international institution like IIASA exist (which orchestrated the building of the model). In Figure 2, which is taken from Streets (1988), the scope of the RAINS-type models is compared with that of two other international RAINS model (ACIDRAIN AND BICKRAM) using the NAPAP framework for integrated models. ACIDRAIN can be seen to much more of a CL module.

To date, the international SR models that have been used in Canada, the "Shaw-Young model" and variations of the "Ontario screening model" work mainly by minimizing the cost of emission control for a desired upper bound on deposition. These models look at a hundred or so sources and receptors in both Canada and the U.S.

Subsequent to the 1983 acid rain negotiations, in which the 20 kg/ha maximum target load was used, several CL models were developed in Canada which have been used to examine the effect of acid rain on watershed acidification and its resulting effect on fish and wildlife. Because these modules were only developed for wet sulphate deposition, they can only be used to answer the question of what portion of certain areas of our environment will not be protected by the North American SO2 emission reductions that are currently or may soon be implemented. These models have not been generalized to all of the affected areas of Canada and do not look at the effects of the deposition of substances other than sulphate.

In addition to CL modules for assessing environmental impact, CL modules are also being developed to assess socio-economic impacts. Preliminary work is currently being undertaken by J. McEwen for Environment Canada. This CL module looks at the effects on the labour force that result from acid rain damage. Critical load modules for LRTAP forest and human health damages are not currently available for Canada.

In the U.S., international SR models have also been developed. One model has been used by the Argonne National Laboratory to test the impact of emission control Bills placed before Congress.

Source receptor (SR) models have been available in two basic forms. The first models used in both Canada and Europe were the Lagrangian models, which are basically linear transport models. These models were used for the 1983 round of North American acid rain negotiations. The output of these models is also used in the RAINS model for Europe.

More recently, Canada has been developing and implementing an Eulerian transport model which is much more complex but, in theory, more accurate and

Table 1. Summary of integrated models of acidic deposition

		Substance				Sector modeled			Output						
		SO2	NOx	VOc	CO2	Util	Ind	Trans	Depo-sition	Econ	Bldg	Lake	Health	Forest	Wild Life
1.	CANADA														
1.1	Ont. Screening Model (SR)	X				X	X		X	X					
1.2	Quebec-MARKAL (SR)	X	X			X	X	X	X	X					
1.3	Shaw-Young (SR)	X				X	X		X						
1.4	Lam,Fraser (CL)	X										X		X	
1.5	Minns, Essa(CL)	X										X			
1.6	Blancher, Essa (CL)	X												X	X
1.7	McEwen (CL)	X								X			X	X	X
2.	U.S.														
2.1	NAPAP (SR,CL)	X	X	X	X		X	X	X	X	X	X		X	
2.2	MARKAL (SR)	X				X	X		X	X					
2.3	ADAM (SR,CL)	X	X						X	X	X			X	
2.4	ADEPT (SR)	X	X			X	X	X	X						
2.5	AIRCOST (SR)	X					X	X	X	X					
3.	EUROPE														
3.1	RAINS (SR)	X	X			X	X	X	X	X		X		X	
3.2	ACID RAIN (CL)	X	X						X	X	X	X	X	X	
3.3	BICRAM	X	X			X	X	X	X	X					
3.4	MARKAL-National (SR)														
	- FRG	X	X		X	X	X	X	X						
	- Neth.	X	X		X	X	X	X	X						
	- Sweden	X	X		X	X	X		X	X					
	- Switzerland	X	X			X	X	X	X	X					
	- U.K.	X	X		X	X	X		X	X					
3.5	MARKAL-Local	X	X			X	X		X	X					
4.	JAPAN														
	MARKAL (SR)	X	X		X	X		X	X	X					

(SR)-Source Receptor model
(CL)-Critical Load model

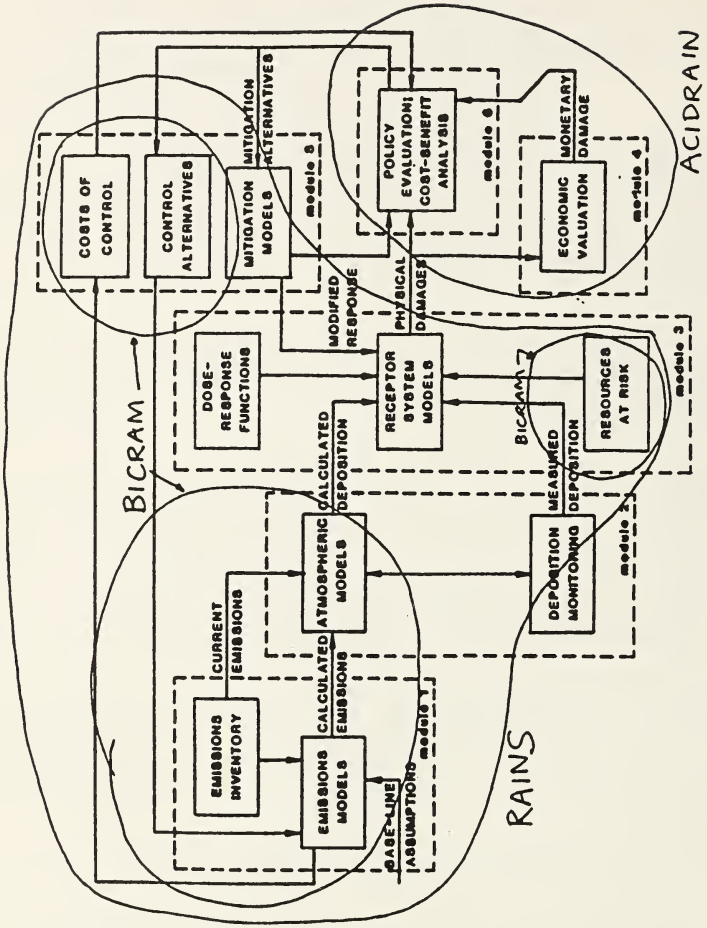


Fig. 2. An "ideal" framework for an integrated assessment model

David G. Streets "A review of acid rain models for Europe" prepared for "The Task Force on Integrated Assessment Modelling", Executive body for the convention on Long Range Trans Boundary Air Pollution. United Nations Economic Commission for Europe, May 6, 1988.

will permit the modelling of the more complex diurnal non-linear ozone problem. While the Europeans have decided that the added precision that would result from using the Eulerian model is not presently necessary, Canada has decided to go ahead and develop the Eulerian model. Whether there will be a policy demand for the output of this more sophisticated model remains to be seen.

NATIONAL MODELS

The major national models in use today are variations of the MARKAL model whose development was begun in the U.S. (Brookhaven National Laboratory) and in the Federal Republic of Germany (Kernforschungsanlage Julich (KFA)). This linear programming model was developed during the oil crisis in 1973 and was originally designed to help a nation decide on efficient energy use and production systems. In order to do this, existing and potential energy production systems were characterized and incorporated into MARKAL. Subsequent to 1983, with the growth of environmental concern and the fading of the oil crisis, many of the MARKAL models were converted to include estimates of SO_2 and NO_x emissions, and more recently CO_2 emissions. Most of the MARKAL model users are in Europe. One exception is in Canada where MARKAL is being developed to choose environmentally sound energy efficient configurations for Quebec. A proposal to do the same for Ontario has been submitted to Environment Canada.

There are two reasons why the national MARKAL models have not been linked together in Europe (or elsewhere) and used in a manner similar to RAINS. Most importantly, the level of detail that exists in the national MARKAL model is not necessary for international LRTAP decision-making. Secondly, due to this level of detail, it would be technically difficult, if not impossible, to perform such a linkage.

Modelling at the local level is a relatively new use of the MARKAL model. The major country in which this has occurred is Sweden; the Energy Research Commission (Efn) has used MARKAL for assessing energy research and development, sensitivity analysis, time variation of shadow prices of heat and electricity, seasonal and daily regulation of hydropower, and the effects of taxes. Under Efn sponsorship, MARKAL is maintained at the Chalmers University of Technology where it has been used for integrated energy-environment planning in four communities: Jonkoping, Varnamo, Uppsala, and Gothenburg. The initial work in Jonkoping was financed by research grants from the Efn. The ongoing work in Uppsala and Gothenburg is financed by the local utilities, and the work in Varnamo by a group of interested parties including the local utility. This local modelling is relevant to Canada as there is a possibility that such an approach could be useful as a tool for solving complex local environmental problems such as that outlined in the Hamilton Harbour Remedial Action Plan.

4. HOW TO MAKE BETTER USE OF INTEGRATED MODELLING TECHNIQUES IN ENVIRONMENTAL DECISION MAKING

Within the Canadian LRTAP decision-making process, computer-based models can be used to assist Canadian decision-makers in choosing the most effective way to reduce emissions to a socially acceptable level.

Canada and the U.S. have the technological know-how to undertake this kind of analysis but the technique has not been as extensively used as in Europe. In the U.S., because of the lack of political will to act on the LRTAP problem, this form of analysis has been mainly used to analyse the environmental implications of LRTAP bills pending before Congress. In Canada, this form of integrated analysis was used as a back-up to validate the 1985 federal/provincial agreements that were reached using fairly simple SR relationships.

Because of the severity and complexity of the pollution problem in Europe, and a different political climate, this form of environmental impact modelling has been and is being used extensively in national energy planning in all of the major European countries (in both the east and west). Moreover the OECD and the ECE have begun to incorporate these tools in European-wide energy/environment planning.

In the preceding sections of this paper it has been argued that in the next 2-5 years, there will be increased demand for modular integrated LRTAP models. Judging from the attitudes of users, these models should probably be broken up into CL modules and SR modules. These modules should cover all of the areas in North America that will be affected by acidic deposition. It is anticipated that the CL modules will not only be used to develop politically acceptable "target loads" for LRTAP acidic deposition but will also be used to estimate the environmental damage that will occur in areas that are not fully protected by the present plans to control sulphur emissions by 1994.

One of the key needs not presently being satisfied is modules that can be used to assess the impact of LRTAP acidic deposition on forests and human health. If these modules were available, it would be possible to examine the crucial question of what should be the overall critical load for each of the LRTAP pollutants for each of the geographical regions.

Once these critical loads have been established, socially acceptable target loads can be developed and SR models can be used to select socially acceptable ways to reduce emissions.

In performing this stage of the analysis, one should not only look at command and control techniques but also at fuel switching and conservation-related reduction.

In light of the expected political climate, it is crucial that these models be available in a user-friendly form within the next few years.

5. ANOTHER POTENTIAL APPLICATION OF INTEGRATED MODELS: PRIORITY SETTING

As the current coordinator of Environment Canada's socio-economic LRTAP program, I have had to deal with the question of how to allocate and justify the use of scarce money resources in support of LRTAP socioeconomic studies. Some would argue that only direct economic effects, such as cost of building repairs, should be considered when assessing the socio-economic impact of acidic deposition. At the other extreme, some argue that, for example, the effect of acid rain on duckweed should be considered a socio-economic problem caused by LRTAP because of the "eventual" socio-economic effect it will have on the human population. Another less extreme example would be a study of trends in the number of lakes that are dying or the percent of loons that are nesting. In

order to determine priorities, I would like to know the total cost of each project, the short and long run deliverables, dates of delivery, and the value of the deliverables to my clients. While the project proponent may be able to estimate the costs of different deliverables, it would be unfair to expect him to define the value of the deliverables. For this, I need the user, my client, to help me assess the value of the different deliverables; and for the scientist to assess the feasi-bility and cost of producing them. Finally, as a coordinator, I want to be sure that my client will understand and will be able to use the results that will be produced.

The same type of questions arise with respect to the type of integrated modelling effort that should be supported by our clients. Referring back to Fig.1, some comprehensive SR models include "physical damages" and in some cases the resulting "monetary loss". If we assume that "physical damages" means "any" physical damage, then we are not any better off in deciding which research study should be supported. Clearly this definition is not very useful. On the other hand, if we support integrated model development that included only monetary damage, then we have also missed the boat since the overall socio-economic impact of acidic deposition is far greater than the directly measurable monetary impacts.

This workshop, then, represents a unique opportunity to begin to order priorities, both for the client and for the scientist. I urge users to define, as best you can, the kinds of scientific and socio-economic results that would be useful to you, as well as delivery date and willingness to pay. The scientist too should try, as best as you can, to define what you can produce, when you can produce it, and how much it will cost.

For those who are here to relate their past experiences, it would also be worthwhile if you could estimate the costs of what you did, the time that it took to produce the results, and the use that was made of your product.

REFERENCES FOR TABLE 1

1. CANADA

1.1 ONTARIO SCREENING MODELS

Ellis, J.H., E.A. McBean and G.J. Farquhar. 1985. Chance-constrained Stochastic Linear Programming Model for Acid Rain Abatement. 1- Complete Colinearity and Non-Colinearity. Atmospheric Environment, 19(6):925-937.

Ontario Ministry of Environment. 1981. Documentation of the Ontario MOE Statistical LRT Model. OME-LRT Work Group 2. Report 2-8. March.

McBean, E.A. 1987. Developing Management Positions for Acidic Emission Reduction Negotiations. Systems Analysis in Water Quality Management, (Ed.) M.B.Beck. Advances in Water Pollution Control, Symposium Proceedings held in London, England, June 30-July 2.

1.2 QUEBEC - MARKAL (SR)

Baillard, D., C. Berger, A. Haurie, R. Loulou, and Simonsen, H. 1987. Modeling Energy/Technology in the Pulp and Paper Industry of Canada: the MARKAL Approach. G-87-01, GERAD, Montreal, Canada, January 1987.

Baillard, D., C. Berger, A. Haurie and R. Loulou. 1987. Modeling Energy/Technology in the Cement Industry of Canada: the MARKAL Approach. G-87-02, GERAD, Montreal, Canada, January 1987.

Baillard, D., C. Berger, A. Haurie and R. Loulou. 1987. Modeling Energy/Technology in the Smelting and Refining Industry of Canada: the MARKAL Approach. G-87-03, GERAD, Montréal. January 1987.

Haurie, A., R. Loulou, J.P Waaub and H. Connord-Lajambe. 1988. A Strategy for Reducing Sulphur and Nitrogen Oxides Contributing to Air Pollution (in Quebec). G-88-04, GERAD, Montreal, Canada, April 1988.

1.3 SHAW-YOUNG (SR)

Young, J.W.S. and R.W. Shaw. 1986. A Proposed Strategy for Reducing Sulphate Deposition in North America I. Methodology for Minimizing Sulpher Removal. Atmospheric Environment, 20:189-199.

Shaw, R.W. 1986. A Proposed Strategy for Reducing Sulphate Deposition in North America Ii, Methodology for Minimizing Cost. Atmospheric Environment, 20(1):201-206.

1.4 LAM-FRASER (CL)

Lam, D.C.L., A.S. Fraser, D.A. Swkayne, J. Storey and I. Wong. 1988. Regional Analysis of Watershed Acidification using the Expert Systems Approach, Environmental Software, 3(3):127-134.

1.5 MINNS, ESSA (CL)

Jones, M.L., D.R. Marmorek, L.P. Rattie, C.H.R. Wedeles and D.S. Slocombe. 1988. Derivation and Analysis of a Model to Predict the Effect of Acidic Deposition on Surface Waters. For Department of Fisheries and Oceans, and Environment Canada, ESSA, Suite 102-66 Isabella Street, Toronto, Ontario M4Y 1N3.

1.6 BLANCHER, ESSA (CL)

Jones, M.L. and C. Wedeles. 1989. Developing a Regional Model of Acidification Effects on Waterfowl. For Canadian Wildlife Service, ESSA, Suite 102, 66 Isabella Street, Toronto, Ontario M4Y 1N3.

1.7 McEwen, J. 1989. Natural Resources at Risk from Acidic Deposition in Eastern Canada. For Canadian Wildlife Service, Sustainable Development Branch, Environment Canada, Ottawa K1A 0H3.

2. UNITED STATES

2.1 NAPAP, AUSM (SR,CL)

Wood, D.A. 1988. Model Evaluation Studies. Task Group Project IA. 2-28 (B2-28b), Report to NAPAP Task Group I Meeting, February, p. 304.

South, D.W., J.J. Bragen, D.A. Hanson and G.A. Boyd. 1988. Advanced Utility Simulation Model (AUSM): Regionalized Projections of End-use Electricity Demand. Argonne National Laboratory, Report ANL/EES-TM-300.

Baughman, M.L., E.R. Berndt, J.A. Fay, D.S. Golomb, J. Gruhl, C.D. Kolstad, F.C. Scheppe and D.O. Wood. 1985. A Review of the State-level Advanced Utility Simulation Model. Massachusetts Institute of Technology, Energy Laboratory, December 1985.

2.2 MARKAL (SR)

Hill, D., J. Lukachinski and J. Lamontagne. 1985. Two Sensitivity Runs of the MARKAL Model of the U.S. Showing Shifts in Fuel Use. BNL 3752, Brookhaven National Laboratory for the U.S. Department of Energy, March 1985, revised September 1985.

Hill, D., V.L. Sailor and L.G. Fishbone. 1981. "Future U.S. Energy Technologies: Cost and Oil-Import Tradeoffs". Energy, 6(12).

2.3 ADAM (SR)

Marnicio, J., E.S. Rubin, M.J. Small and J. Henrion. 1986. Acid Deposition Assessment Model: An Integrated Framework for Benefit and Cost Analysis. Center for Energy and Environmental Studies, Carnegie Mellon University, Pittsburgh, PA, August 1986.

2.4 ADEPT (EPRI,ERAM) (SR)

McGowin, C.R., D.J. Leadenham, J.B. Parkes, M.J. Miller and S.C. Fan. 1986. Sensitivity Analysis of Electric Utility Sulfur Dioxide Emissions in the U.S. Electric Power Research Institute, Coal Combustion Systems Division, Palo Alto, CA.

McGowin, C.R., D.J. Leadenham, S.C. Fan and M.J. Miller. 1986. Sulfur Dioxide and Nitrogen Oxides Emission Trends and Control Costs. Electric Power Research Institute. Memo to K. Yeager, December 11, 1986, Palo Alto, CA. 1986.

2.5 AIRCOST (ANL, ETAM) (SR)

E.H. Pechan and Associates, Inc. AIRCOST Model: Technical Documention. Report prepared for U.S. Environmental Protection Agency, Washington, DC. 1983. The Environmental Trends Analysis Model: User Documentation and Technical Documentation. Springfield, VA, 1984.

Silverman, B. 1985. Heuristics in an Air Pollution Control Cost Model: The "AIRCOST" Model of the Electric Utility Industry. Management Science, 31:1030.

Garvey, D.B., P.J. Grogan, D.A. Hanson, D.G. Streets and L.D. Carter. The Bubble Policy: A Preliminary Analysis for the State of Illinois. ANL/EES-TM-200, Argonne National Laboratory, Argonne, Illinois.

Garvey, D.B., D.G. Streets and T.D. Veselka. 1984. The "Control-or-Retire" Strategy for Reducing Sulfur Dioxide Emissions from Power Plants. ANL/EEL-TM-283, Argonne National Laboratory, Argonne, Illinois.

Placet, M., D.G. Streets and E.R. Williams. 1986. Environmental Trends Associated with the Fifth National Energy Policy Plan. ANL/EES-TM-323.

Streets, D.G. 1986. Opportunities for Improving the Cost-effectiveness of Acid Rain Control Strategies. Environmental Progress, 5(w):82.

Streets, D.G., J.E. Vernet and T.D. Veselka. 1984. Proposals for Acid Rain Control from the 98th Congress. ANL/EES-TM-281, October 1984.

Streets, D.G., D.A. Hanson and L.D. Carter. 1984. Targeted Strategies for Control of Acid Deposition. J. Air Pollution Control Association, 34(12):1187.

Veselka, T.D., D.A. Hanson, R.C. Hemphill, C.A. Hoffstetter, D.W. South and D.G. Streets. 1987. An Analysis of the Silorski Bill, H.R. 4567, to Control Acid Rain. ANL/EES-TM-338, Energy and Environmental Systems Division, Argonne National Laboratory, Argonne, Illinois.

3. EUROPE

3.1 RAINS (IIASA)(SR,CL)

Alcamo, J. et al. 1988. Acidification in Europe: A Simulation Model for Evaluating Control Strategies. Ambio, 16:232.

Batterman, S. et al. 1986. Optimal S02 Abatement Policies in Europe: Some Examples. IIASA Working Paper WP-86-42, August 1986.

Alcamo, J. and J. Bartnicki. 1987. A Framework for Error Analysis of a Long-Range Transport Model with Emphasis on Parameter Uncertainty. Atmospheric Environment, 21:2121.

Amann, M. and G. Kornai. 1987. Cost Functions for Controlling S O 2 Emissions in Europe. IIASA Working Paper WP-87-065, May 1987.

3.2 ACID RAIN (CL)

Watson, S.R. and C.W. Hope. 1987. ACIDRAIN: A Model for Analyzing the Costs and Benefits of Pollution Control. Cambridge Decision Analysts, England, Final Report, October 1987.

Hope, C.W. 1987. An Investigation with ACIDRAIN. Cambridge Decision Analysts, United Kingdom, October 1987.

Hope, C.W. and A.L. Hope. 1987. "ACIDRAIN": A User's Reference Guide. Cambridge Decision Analysts, England, October 1987.

Streets, D.G. 1988. A Review of Acid Rain models for Europe. The Task force on Integrated Assessment Modelling Executive Body for the Convention on Long Range Trans Boundary Air Pollution. United Nations Economic Commision for Europe, May 6, 1988.

3.3 BICRAM

Beijer Institute. 1987. Acid Deposition in Europe: Co-ordinated Abatement Strategies. An Interim Report, Beijer Institute Centre for Resource Assessment and Management, University of York, England.

3.4 MARKAL-NATIONAL (SR)

Federal Republic Germany

Bellman, K., T. Brenner, G. Eickhoff, G.V. Kortzfleisch, W. Mends, K. Schmitz, D. Sievert, W. Terhorst and A. Voss. 1982. Energie fur den Verkehr - Eine systemanalytische Untersuchung der langfristigen Perspektiven des Verkehrssektors in der Bundesrepublik Deutschland und dessen Versorgung mit Kraftstoffen im energiewirtschaftlichen Wettbewerb. November.

The Netherlands

Boswinkel, H.H., D. Gerbers, T. Kram, P. Lako, P.A. Okken and D.N. Tiemersma. 1987. Energie Onderzoek Scenarios (Energy Research Scenarios) EOS-76. Energie Studie Centrum, Petten, November (in Dutch).

Boswinkel, H.H. and P.A. Okken. 1988. Opportunities for Gas Absorption Heat Pump Development. Energy Study Centre, Petten, June.

Okken, P.A. 1988. Impact of Environmental Constraints on Energy Technology: the Case of NO_x in The Netherlands. Energy Study Centre, Petten, May.

Sweden

National Energy Administration and National Environmental Board. 1987. Less NO_x from Combustion: An Investigation of Ways of Reducing NO_x. Report 1987 3 (in Swedish).

Energy Research Commission. 1983. An Energy RD&D Strategy - A Planning Document. Report 3:1983.

Bergendahl, P.A. and C. Bergstrom. 1980. Long Term Energy Options for Sweden: the IEA Model and Some Simulation Results. Energy Research and Development Commission, Energy Systems Research Group, DFE Report No. 36.

Wene, C.O. The Optimum Mix of Conservation and Substitution: An Example from Retrofitting of Old Buildings. Int. J. Energy Research, 4:271-281.

Switzerland

Kypreos, S. and J. Wochele. 1988. Analysis of the Swiss Energy Supply System Using MARKAL. EGES Arbeitsdokument Nr. 15, EDMZ.

United Kingdom

Finnis, M.W., R.C. Perrin and H.G. Tolland. 1985. The Ranking of Renewable Energy Technologies in Variant Scenarios. AERE R 11861, Theoretical Physics and Energy Technology Divisions, Harwell Laboratory, Oxfordshire, July (in Confidence).

3.5 MARKAL-LOCAL (SR)

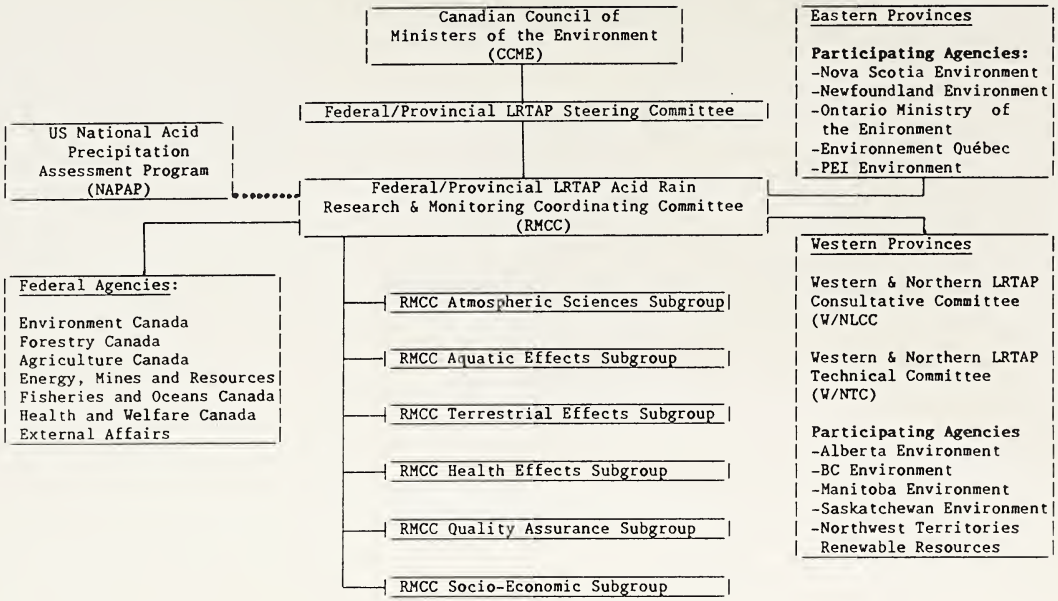
Wene, C.O. 1988. Using a Comprehensive Model for Community Energy Planning. In: Spatial Energy Analysis: Models for Strategic Decisions in an Urban and Regional Context, (Eds.) L. Lundqvist, L.G. Mattson, and E.A. Eriksson. Gower Press.

Wene, C.O. and B. Ryden. 1988. A Comprehensive Energy Model in the Municipal Planning Process. European J. Operations Research, 33(2):212.

4.0 Japan (SR)

Koyama, S., Kashihara, T., Endo, E. of ETL, Yasukawa, S., Mankin, S. and Yonese, H. of JAERI. 1982. Result of Phase-B Scenario Run of Japan, presented at the IEA/ETSAP Scenario Workshop in Dublin, October 1982.

LRTAP COMMITTEE STRUCTURE



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